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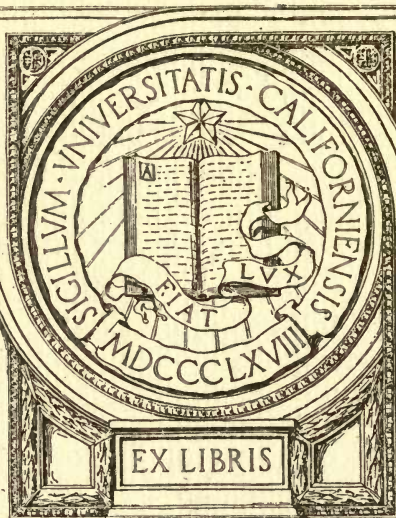
PHYSICAL LABORATORY HANDBOOK

GEORGE A. HOADLEY

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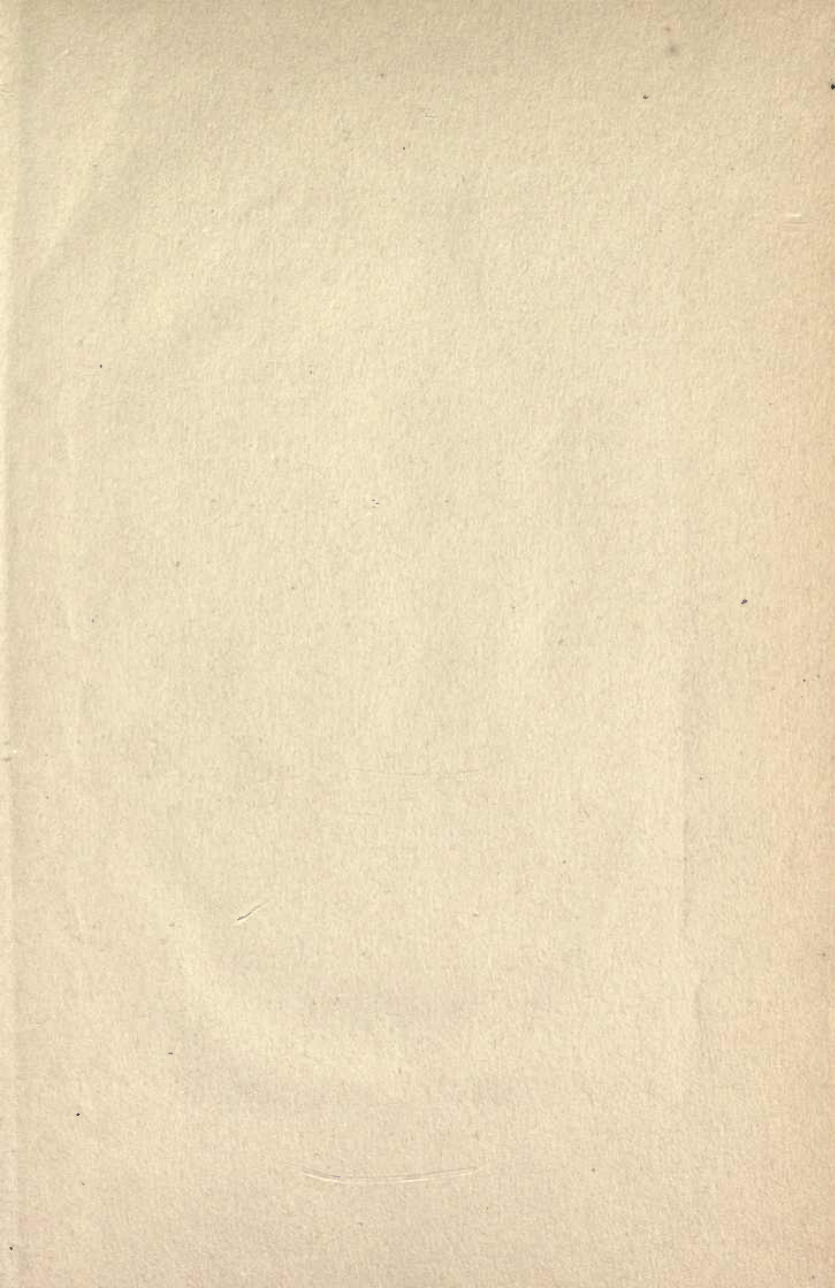
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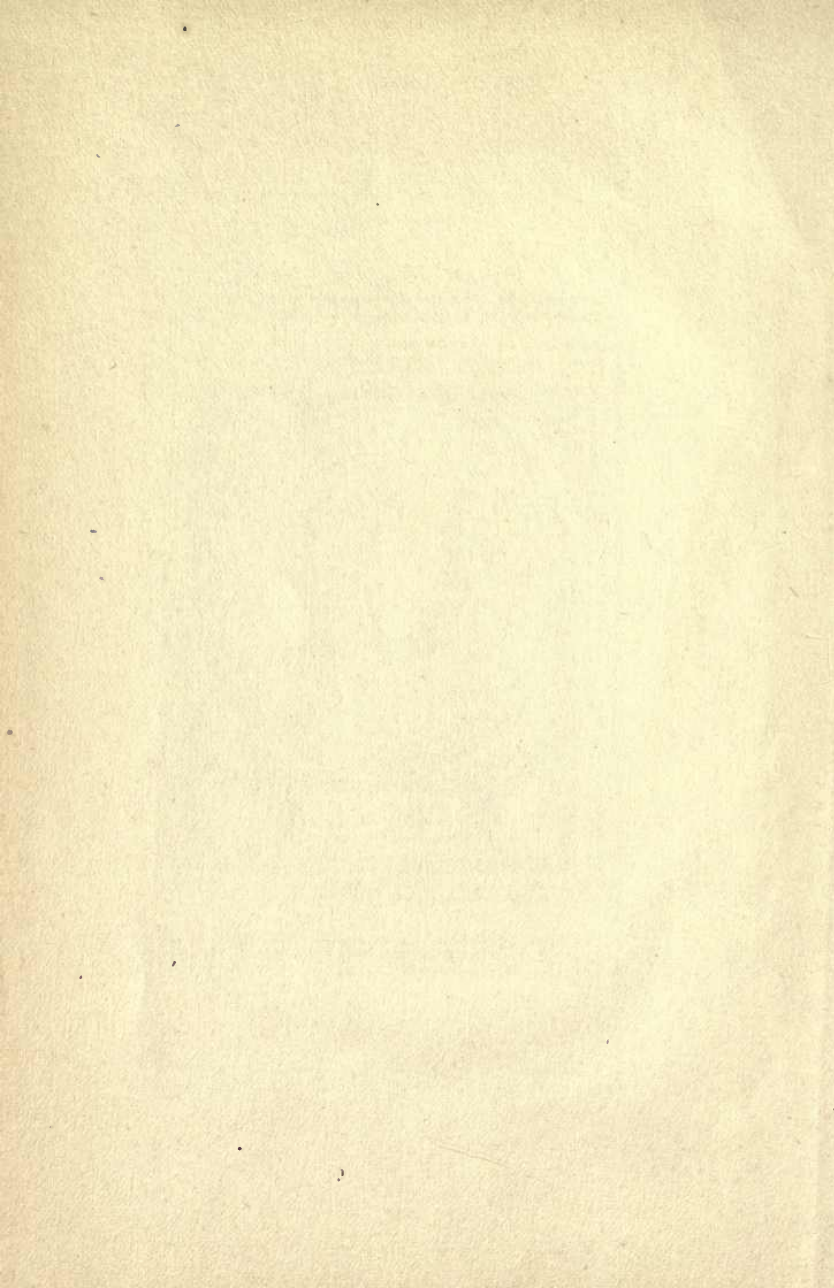
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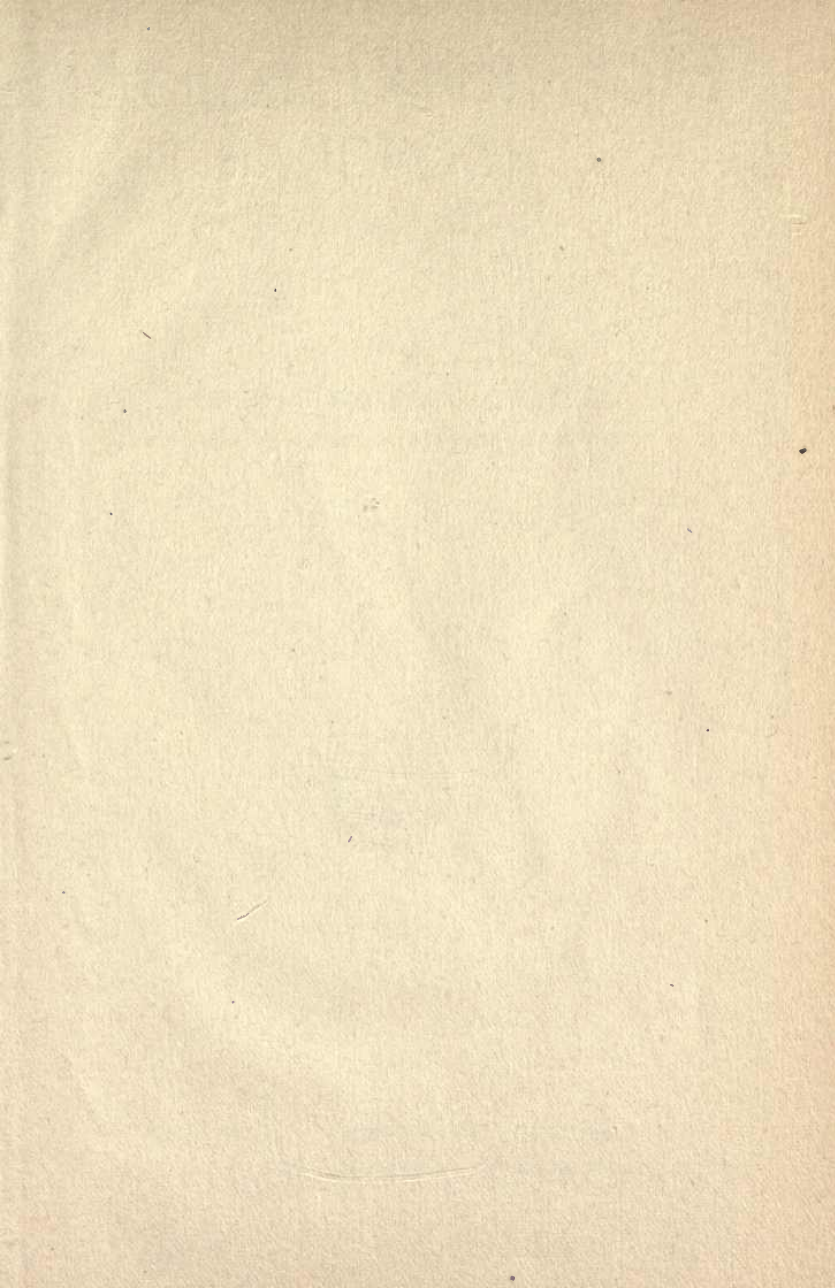


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PHYSICAL LABORATORY HANDBOOK

BY

GEORGE A. HOADLEY, C.E., Sc.D.

PROFESSOR OF PHYSICS IN SWARTHMORE COLLEGE



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PREFACE

THIS book is designed to provide a suitable number of experiments for a course in Physics, including those needed to meet the entrance requirements of colleges and universities. It will be found especially convenient in the schools that use the author's "Elements of Physics" as a text-book, because the order of subjects is the same; but it can be used also in connection with other texts.

An attempt has been made to avoid a too detailed description of apparatus or method of experimentation and rather to give suggestions from which the pupil, with the assistance of his instructor, can work out such details as the apparatus at hand will require. A pupil generally learns more from an experiment if he devises his own apparatus than he does if he uses apparatus provided for him.

Tables of physical constants are omitted for the reason that they are to be found in most text-books of Physics and because every laboratory should be equipped with at least one copy of the "Smithsonian Physical Tables." This book is not expensive, and it furnishes all the tables that are likely to be needed for reference. Hering's "Conversion Tables" is also a desirable reference book.

The form of notebook to be used by the pupil in which to record the work done in the laboratory, is left to the discretion of the teacher. Colleges and universities generally require a certificate for the notebook, in a form which can be obtained from them.

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PHYSICAL LABORATORY HANDBOOK

SUGGESTIONS FOR EXPERIMENTING

FOR success in the experimental work outlined in this book it is necessary that the following general directions be carefully observed.

Read the directions, with care, before beginning to make the experiment.

In every step in the making of the experiment and in the keeping of the notes, be accurate, careful, precise, and neat.

Record all observations at the time they are made, in such a way that the record will be permanent. Care should be taken to record the exact observations made, whether these are in agreement with previous ideas or not.

Observations should be repeated under the same conditions until it is evident that correct results are obtained. The final reading should be the average of a set of readings.

In all cases in which a scale reading is taken an estimate must be made of the tenths of a division beyond the last unit reading.

The conditions best suited to secure the greatest accuracy should be chosen.

The graphical method (as illustrated in Fig. 11, p. 22) is frequently the best way of recording the results of an experiment so that they can be easily interpreted.

When the observations have been made and the results obtained, a detailed report should be written, containing:—

1. A statement of the object of the experiment and the method employed.

2. A description of the apparatus used.
3. A proof of the accuracy of each formula when first used.
4. All the original data and a description of all work done in obtaining results.
5. The curves obtained by the graphical method if that is applicable.
6. A comparison of the results obtained with former published results.

Word and arrange the report accurately and clearly.

Guard against the following kinds of errors: errors of method; inaccuracies of instruments; accidental errors of observation; mistakes in calculation.

However well the experiments may have been made and however accurately the results have been recorded, the student should not be satisfied unless he gets, as the result of this work, a better grasp of the phenomena and their interpretation.

HINTS FOR SIMPLE LABORATORY PROCESSES

There are certain simple laboratory processes about which every worker in a laboratory should know. Successful methods of working will come to those only who are willing to work for them. Personal manipulation alone can give facility in laboratory working, and the hints that are given here are simply directions concerning the things that every one should know.

To clean glass.—Wash thoroughly in succession with chromic acid, distilled water, and alcohol. In some stubborn cases caustic potash may be used, after which the dish must be thoroughly rinsed with distilled water. Caustic soda must not be used, as it would corrode the glass.

To dry out a glass flask.—Force dry air into it through a long glass tube that is kept hot by a Bunsen flame. Use a foot pump for forcing the air and see that it is kept free from dust.

To clean mercury.— Draw out one end of a glass tube, of 5 or 6 mm. internal diameter and a meter long, into a narrow tube, and bend it into a double U as shown in Fig. 1. Fix it in a vertical position and pour into it a little clean mercury to fill the lower end. Fill the tube nearly to the top with a 10 % solution of nitric acid. Put a cork stopper in the top of the tube, through which pass a funnel that has been drawn out to a capillary end. Pour the mercury to be cleaned into the funnel. It will fall through the acid in a stream of fine drops and may be collected in a dish placed to receive it at the end of the U tube.

To cut a glass tube.— (a) If the tube is small: Cut a nick in the tube at the proper place with a sharp triangular file. Grasp the tube with both hands with the nick outward. Place a thumb on each side of the nick on the opposite side of the tube. Bend the tube back across the tips of the thumbs and pull it apart at the same time, and the tube will come in two with even ends. (b) If the tube is large: File a deep nick in the tube. Wind two long strips of filter paper around the tube, one on each side of the nick, and tie them on with thread. The edges of the paper facing the nick should be even and parallel, and not more than an eighth of an inch apart. Dampen the paper with a few drops of water. Start a crack at the nick with the fine point of a blowpipe flame and lead it around the tube. If carefully done, this method will give even ends.

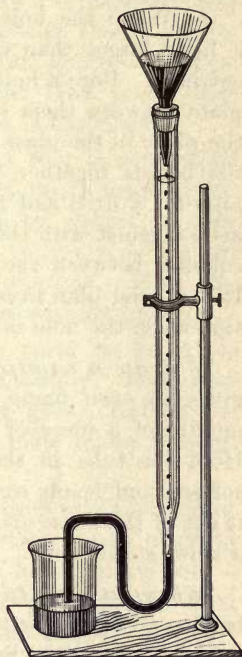


FIG. 1. CLEANING MERCURY.

To bore a hole in a glass plate. — (a) When the hole is small: Use for a drill the end of a small rat-tail or triangular file, moistening the glass with turpentine in which camphor has been dissolved. Work the drill by hand, and if it becomes dull, break off a piece of the end with forceps.

(b) When the hole is large: Cut two pieces of board each a little larger than the glass plate which is to have the hole cut in it. Bore a hole in the upper board and place the glass plate between them so that this hole shall come exactly over the place in the glass plate where the hole is to be cut. Clamp the boards together with wood screws. Use a piece of gas pipe for a drill and feed it with emery or carborundum, and keep it moist with the camphor solution. Rotate this drill by rubbing between the hands, pressing lightly upon the drill. It is a good plan to reverse the plate and drill from the other side when the hole is nearly through.

To draw a capillary tube. — Choose a fish-tail burner that gives an even flame two and a half inches wide. Heat the middle of a piece of small tubing 20 cm. long in this flame. Hold the tube in the luminous part of this flame until it softens and bends easily. When it is uniformly heated, take it out of the flame and draw it to the required dimensions with a slow, steady pull.

To bend a glass tube. — Heat the tube, at the part where the bend is to be, in the luminous flame of a fish-tail burner. Rotate the tube in the fingers until it is equally heated, and until it will bend freely. Remove it from the flame and bend it to the desired form by a steady pressure. Do not pull the tube much or it will be reduced at the bend. If the Bunsen burner is used, there is danger of heating the tube unevenly, so that the bend will not be symmetrical.

To close the end of a glass tube. — Break the tube squarely off at the point selected. Hold the end vertically in the hottest part of the Bunsen flame and turn it slowly until the end

is melted and closed. The molten glass will run together into the form of a sphere, just as any liquid will as the result of capillarity, and the end will be evenly rounded if the heating is right.

To use sealing wax.—In order to make a satisfactory sealing-wax joint it is necessary that the articles should first be heated and have a thin coating of the wax applied. Reheat both articles until the wax is melted and then press them together until they are cooled and the wax is hardened.

Universal wax.—A form of soft wax that is very useful for making temporary joints and connections is made as follows: Thoroughly work together 4 parts, by weight, of bees-wax and 1 part of Venetian turpentine. Color it by mixing with this a sufficient quantity of red vermilion. With this wax a joint can be made by pressure alone, without heating.

To glue wood together.—Shape the parts to be glued together so that they fit each other accurately. Heat each part and coat it with a thin coating of glue. Reheat and press the parts firmly together and leave them under pressure until the glue has hardened.

To solder a wire joint.—First, clean each wire thoroughly. This is best done with chloride of zinc, which can be made by dropping small pieces of zinc into dilute hydrochloric acid—enough zinc should be put in to make a saturated solution. "Tin" each clean wire separately with the solder. Ordinary tinman's solder will answer for most laboratory purposes. Wind the tinned ends of the wires together and heat in the flame of an alcohol lamp, adding more solder if needed.

To solder with the soldering iron.—In order that a soldering iron, or copper, shall work properly it must be thoroughly clean. Chloride of zinc, resin, or borax may be used for the purpose of a flux. Turn up the edges of a small piece of tin plate and in it put a little flux (a few drops of zinc chloride, for example) and a small bit of solder. Heat the iron until

it will melt the solder, and then work it back and forth across the tin, and the solder will flow over the entire surface of the iron. This is called "tinning" the iron. If the surfaces of the metals to be soldered are clean, and the iron hot enough, — about 200° C. for ordinary solder, — a good job can readily be obtained with a little care.

In order that the soldered joint may be a permanent one it must be washed thoroughly to remove all traces of the zinc chloride. Resin or some form of commercial flux is better than zinc chloride for use in soldering joints that are to be used for electrical work.

EXPERIMENT 1

Measurements of Lengths, Areas, and Volumes. Elements of Physics, pp. 13-15

Apparatus. — A rectangular block of wood, having three different dimensions; two scales, one having centimeter and millimeter divisions and the other inches and parts of the inch; an overflow tank and catch basin; a graduate; paraffin; gas flame or lamp.

Method. — Rest the block firmly upon a table and place the scale upon it in such a way that the edge upon which the divisions are marked shall come next to the block. Move the scale until some one division is exactly opposite one edge of the block (Fig. 2), and read the other edge by taking the whole number of divisions plus the tenths of a division between the last mark on the scale coming upon the block and the edge of the block. The

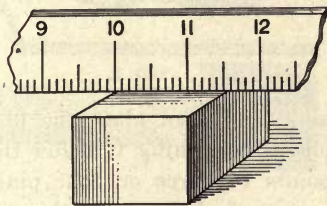


FIG. 2.

The difference between the readings of the two ends is the length of the block. The *estimation of tenths* of a division is very important in measurement, and the accuracy with which it is done makes a large part of the difference between a good measurement and a poor one. Suppose that the width of the block is greater than 15 and less than 16 mm. as shown in Fig. 2. The value of the reading will depend upon the judgment of the reader. The reading of Fig. 2 should be 15.4, not 15.3 or 15.5.

If the block is not perfectly rectangular, take several measurements of each side and take the average of all of these for the dimension of that side.

Compute the areas of all of the faces of the block in both square centimeters and square inches. $\text{Area} = \text{Length} \times \text{Breadth}$.

Compute the volume of the block in both cubic centimeters and cubic inches. In a rectangular block, $\text{Volume} = \text{Area of end} \times \text{Length}$.

Melt a piece of paraffin in a small dish and spread it over the sides of the block. Heat the block over the flame until

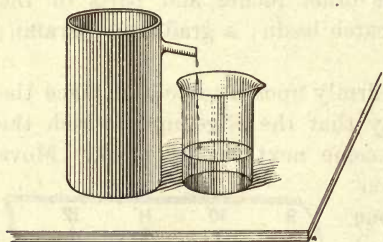


FIG. 3.

the paraffin is absorbed by the wood. This fills the pores of the wood, and prevents the absorption of water. Fill the overflow tank (Fig. 3) with water and let the overflow run into the catch basin. Empty the basin, replace it under the spout of the

tank, and then place the block in the tank. Submerge the block by pushing it below the surface of the water with the points of three or four pins that have been pushed through a thin piece of wood or a heavy card. Find the volume of the displaced water by measuring it in a graduate. In reading the surface of water in a graduate read the bottom of the curved surface, as shown in Fig. 4, and estimate to the tenths of the smallest division.

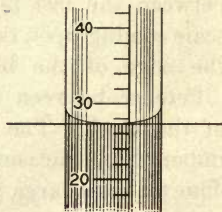


FIG. 4.

Conclusion. — How does the computed volume compare with the volume of water forced out of the tank by the submerged block in the displacement method?

Suggested Experiments. — Find by measurement the dimensions and compute the areas of (a) a right triangle; (b) an isosceles triangle; (c) a page of this book, each margin, and the part covered by the printing.

Find by the displacement method the volume of an irregular solid.

Find by the same method the weight of water displaced by a floating body, and compare it with the weight of the body.

EXPERIMENT 2

To find the Surface and Volume of a Cylinder and of a Sphere. El. of Phys., p. 15

Apparatus. — A cylinder of hard wood (a section of curtain pole will answer); a steel ball such as is used in ball bearings (a large one is preferable); a vernier caliper¹ (if there is one in the laboratory); two rectangular blocks; scales.

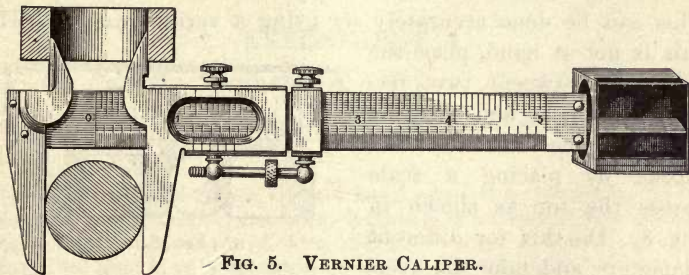


FIG. 5. VERNIER CALIPER.

¹ The vernier is used to measure accurately fractional parts of the smallest divisions of the scale. The simplest form is one in which nine of the smallest divisions — mm. for example — are divided into ten equal parts which are placed upon a movable scale that slides along the first. The article to be measured is placed between the fixed end *P*

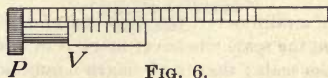


FIG. 6.

and the end of the sliding vernier *V* (Fig. 6), and the reading is taken from both the scale and the vernier. If the scale in Fig. 6 represents millimeters, the reading is 5.3 mm. Since the length of each division of the vernier is 0.9

Method.—(a) *To find the area of a cylindrical surface.*

Measure the length of the cylinder in centimeters and inches. Measure its circumference as follows: Lay the cylinder on a sheet of paper so that a radial mark on the end is exactly over

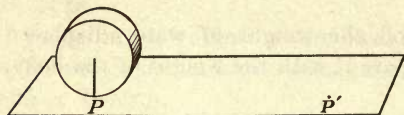


FIG. 7.

a point P , marked on the paper (Fig. 7). Roll the cylinder over once, being careful that it does not slip, and make a mark P' on the paper where

the radial mark on the end of the cylinder touches it the second time. Measure the distance between the two points. This gives the circumference of the cylinder. Compute the area from the formula, $\text{Area} = \text{Length} \times \text{Circumference}$.

(b) *To find the volume of a cylinder.*

In order to do this it is necessary to measure the diameter. This can be done accurately by using a vernier caliper. If this is not at hand, place the cylinder between two rectangular blocks and measure the distance between the blocks by placing a scale across the top as shown in Fig. 8. Do this for different diameters, and take the average as the diameter of the cylinder. Substitute the proper numbers in the formula for the volume of the cylinder,

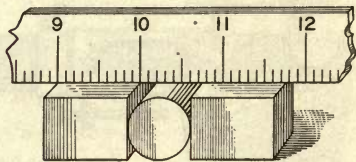


FIG. 8.

of a millimeter, the zero end of the vernier is 0.3 mm. from the 5-mm. mark on the scale whenever mark 3 of the vernier is opposite the 8-mm. mark on the scale; that is, the mark 3 mm. farther on. If the vernier is placed so that mark 6 of the vernier is opposite any mark in the scale, then 0.6 mm. must be added to the millimeters read on the scale up to the zero end of the vernier. Figure 5 shows the method of using the vernier caliper in measuring the diameter of a cylinder, an inside diameter, or a depth.

Volume = Length $\times$ Area of end, and find the volume in cubic inches and cubic centimeters.

NOTE. — Area of circle = πr^2 , in which r is the radius of the circle and π represents the ratio of the circumference of a circle to its diameter, or nearly 3.1416.

(c) *To find the surface of a sphere.*

Measure the diameter of the steel ball in the same way in which you measured the diameter of the cylinder in (b). Substitute the proper values in the formula, Surface of Sphere = $4\pi r^2$.

(d) *To find the volume of a sphere.*

Substitute proper values in the formula, Volume of sphere = $\frac{4}{3}\pi r^3$.

Suggestion. — From your measurements of the circumference of the cylinder in (a) and of the diameter in (b) compute the value of π . The more accurate your measurements, the nearer your result will approximate the true value.

EXPERIMENT 3

To find the Diameter of a Wire. El. of Phys., p. 15

Apparatus. — A micrometer caliper¹ and several sizes of insulated wire.

¹ The micrometer caliper, or sheet metal gauge, is an instrument for the accurate measurement of distances. It consists of a U-shaped piece of brass or steel *A*, through one arm of which is threaded a screw *B*, which is turned by the milled head *C*, or by the ratchet head *R*, and which may be locked in any given position by means of the collar *F*. On the inner metal sleeve *D* there is

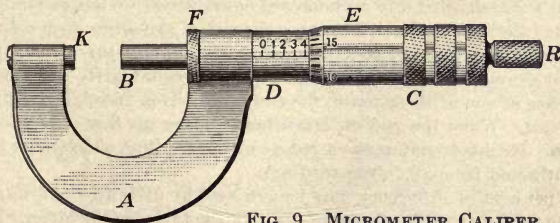


FIG. 9. MICROMETER CALIPER.

Method. — To measure the diameter of an insulated wire hold the wire between *K* and the end of *B* (Fig. 9), and turn *R* up until the ratchet clicks, when the wire will be lightly held

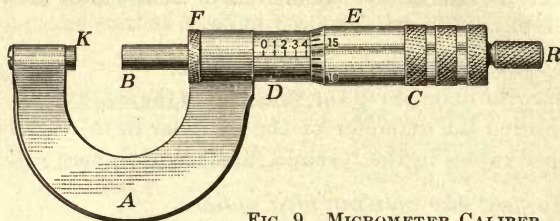


FIG. 9. MICROMETER CALIPER.

between the jaws. (If your caliper has no ratchet head *R*, turn *C*; but *C* should be held loosely between the thumb and finger, and no pressure must be put upon it.) The diameter of the wire will be the sum of the readings on the scale *D* and the circular scale *E*. Take five different readings and average the result for the diameter.

Unwind the insulation from the wire and take readings of the diameter of the uncovered wire.

Subtract this reading from the first to get the double thickness of the insulation.

Look in a wire table to find the number of the wire. Note the difference between your measurement and the diameter given in the table. Determine the per cent ¹ of difference.

a longitudinal scale, the divisions of which are the same as the distance between the threads of the screw. On the end of the outer sleeve *E* there is a circular scale, divided into a number of equal parts. When the milled head *C* is turned through one complete turn, the end of the screw *B* moves toward or away from *K* a distance that is equal to the pitch of the screw, one millimeter, for example. If the circular scale has 50 equal parts and *C* is turned the distance of one of these parts, the end of *B* moves through one fiftieth of a millimeter. When the end of *B* touches the face of *K*, both scales should read zero. If they do not, make a record of the reading, which must be added to or subtracted from all future readings.

¹ The per cent of difference may be obtained by dividing the difference between the reading and the diameter given in the table by the latter.

Record your results somewhat as follows:—

NUMBER OF READING	DIAMETER WITH INSULATION	DIAMETER WITHOUT INSULATION
1	1.81 mm.	1.02 mm.
2	1.87	1.01
3	1.85	1.01
4	1.82	1.02
5	1.78	1.01
Sum	9.13	5.07
Average	1.826	1.014

Thickness of insulation = $(1.826 - 1.014) \div 2 = 0.406$ mm.
 1.014 mm. = 0.03992 in., or 39.92 mils. (1 mil = 0.001 inch.)
 The number nearest to this in the table (El. of Phys., p. 330)
 is 40.3, and this number is for wire No. 18. The per cent of
 difference is $(40.3 - 39.92) \div 40.3 = 0.009 = 0.9\%$.

Suggested Experiments.—Use the micrometer caliper to determine the volume of small cylinders and bicycle balls. Measure the thickness of sheet metal, tin, and brass, and of the paper in this book.

EXPERIMENT 4

To find the Mass per Unit Volume or the Density of a Body. El. of Phys., p. 16

(a) *When the body is of regular form.*

Apparatus.—The rectangular block used in Experiment 1; a balance and weights.

Method.—Weigh the block and divide its mass thus found by its volume already found. This will give the density of the block or its mass per unit volume.

The density of a body is usually given in grams per cubic centimeter. It may be given in pounds per cubic foot. Compute the density of the block in terms of these units.

To weigh the body, first examine the balance to see if the pointer stands at zero when the pans are empty. If it does not, turn the adjusting screw at the end of one of the arms, until the pointer reads zero. Find by trial whether the pans are interchangeable or not. If they are not, mark the pans "right" and "left." Place the body upon one pan and a weight that you think is heavier upon the other pan. If the weight selected is lighter than the body, replace it by a heavier one. If it is heavier than the body, remove it from the pan and put on the next lighter one. Repeat until you have a weight lighter than the body. Leave this weight on the pan and add the next lighter weight. Continue the process by taking every weight in order, putting back into the weight box those that are too heavy and leaving the others on the pan until the body is balanced. The sum of the weights in the pan is the weight of the body. Always use the pincers provided for lifting the weights, and place them upon the pans carefully. A support placed under one of the pans will reduce the swing and bring the arms to balance more quickly.

(b) When the body is of irregular form.

Apparatus. — A graduate; balance; weights and thread.

Method. — Weigh the body and call its mass m . Pour water into the graduate and take a reading. Tie a thread to the body and suspend it in the water. See that all air bubbles are removed from it. Take a second reading. Take the difference between the two readings as the volume of the body and call it v . If the graduate is calibrated in cubic centimeters, the density will be found by dividing m by v .

Conclusion. — How do you know that the difference between the two graduate readings is the volume of the body? Why should all air bubbles be removed from the submerged body?

Suggested Experiments. — Find the density of the cylinder and sphere measured in Experiment 2, after using paraffin to protect the wood as in Experiment 1.

EXPERIMENT 5

To study the Relation between the Force acting upon an Elastic Body and the Distortion produced by it.

El. of Phys., p. 22

(a) *Elasticity of traction.*

Apparatus. — A spiral spring (if no other spring can be found, make use of the kind of spiral spring used to close screen doors); a metric scale mounted vertically; a set of weights.

Method. — Fasten the spring rigidly to a support, as shown in Fig. 10. Straighten out the wire of the spring at the lower end and solder a horizontal pointer to it. Suspend a weight pan from the spring. Place the metric scale in such a position that the end of the pointer is close to its face. Take a reading in millimeters and tenths (estimated) and record this as the zero reading. Put a 5-g. weight¹ in the pan and read the elongation. Take a series of readings, adding 5 g. at a time, until there is a maximum load of 50 g. Take a second series of readings as you remove the weights, 5 g. at a time, until the load is zero.

Conclusion. — Take the average of the two readings as the elongation for each different load. Draw a curve, represent-

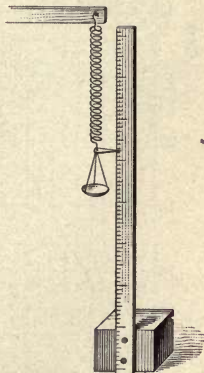


FIG. 10.

¹ The size of wire used for the spring will determine the value of the weights to be used as loads. If the wire is large, the weights would need to be greater.

ing the loads by vertical distances and the elongations of the spring by horizontal distances.

In accordance with Hooke's Law the curve should be a

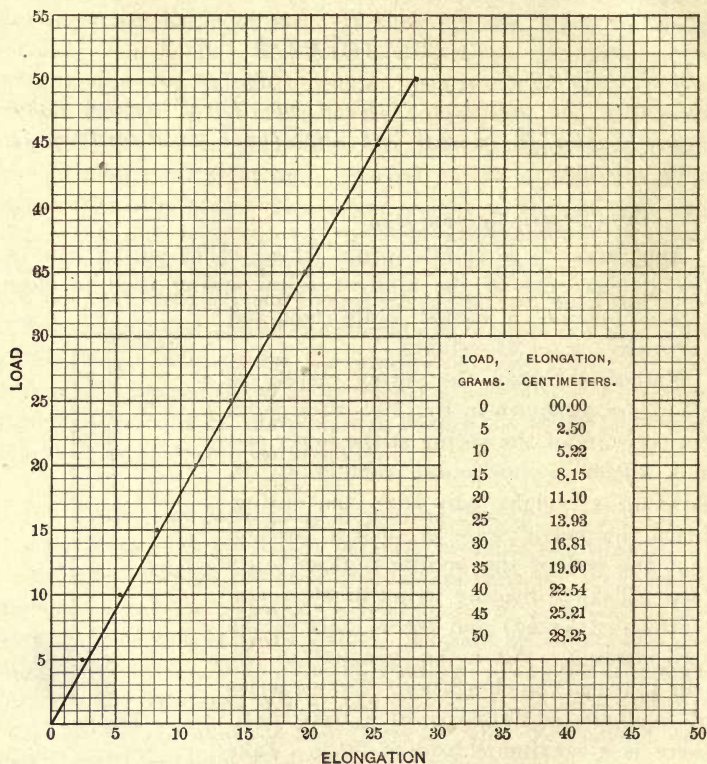


FIG. 11.

straight line. Figure 11 shows the tabular results of an experiment with the curve obtained from them.

Suggested Experiment. — Calibrate the scale of a Jolly balance. (Find the value of the scale divisions.) The Jolly balance is a sensitive form of spring balance shown in Fig. 12.

There are two scale pans, the lower of which can be submerged in water to check the vibrations of the spring. The readings are taken by sighting across the top of a bead carried by the spring wire and noting the position of its image in a mirror scale carried by the standard of the balance.

Are the divisions on an ordinary spring scale the same distance apart? Tell why in your notes. A satisfactory method of reading the elongation of the spring in the Jolly balance is to use a reading telescope. This consists of a telescope which can be moved up and down a vertical stand, always pointing in a horizontal direction. By placing the vertical scale directly behind the spring, the position of some definite mark at the lower end of the spring can be read accurately.

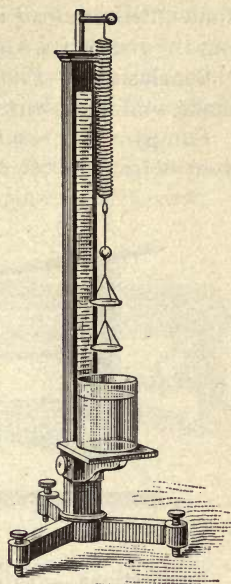


FIG. 12. JOLLY
BALANCE.

(b) *Elasticity of bending.*

Apparatus. — A rectangular wooden rod, 15 mm. by 5 mm. and over a meter long; vertical metric scale; scale pan; weights; and a support, shown in Fig. 13.

Method. — Fix the uprights exactly one meter apart and bore a hole through the brace between them. Place the rod on its side on the uprights. Suspend the scale pan from the middle of the rod, carrying the suspension through the hole in the brace, and set up the scale behind the rod. Take the zero reading when only the weight holder is on the rod. Take a series of readings with loads of 50 g., 100 g., and so on up to 500 g., increasing the load 50 g. for each reading. Take a second series of readings as you decrease the load 50 g. at a

time until zero load is reached. Repeat the experiment, turning the rod on its edge.

Conclusions.—From the average results in each experiment make a table showing the relation of load to amount of bending.

Compare the results of the two experiments and state in your notes the best way to place the floor timbers of a house.

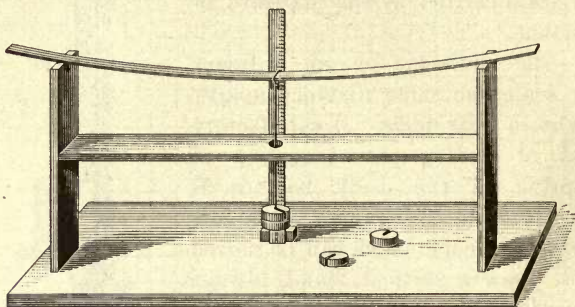


FIG. 13.

Suggestions.—Substitute a steel rod for the wooden rod and repeat.

Fasten the rod at one end and suspend a scale pan from the other and make the experiment.

If your laboratory has the apparatus for finding the elasticity of torsion, make that experiment.

EXPERIMENT 6

To find the Breaking Strength of a Wire. El. of Phys.,
p. 25

Apparatus.—A wire tester (Fig. 14); spring brass wire Nos. 24 and 27; micrometer caliper.

Method.—Thread one end of wire No. 27 through the hole in the crank shaft of the tester and fasten it. Fix the proper length of wire to the scale. Turn the handle of the tester,

being careful that the pawl moves freely over the toothed wheel. Push down steadily upon the wedge in order to prevent the flying back of the balance when the wire breaks. Turn the crank handle steadily and slowly to avoid sudden changes in pressure.

Make three tests for this size of wire and take the average for the breaking weight. Measure the diameter of the wire.

Make the same tests with wire No. 24.

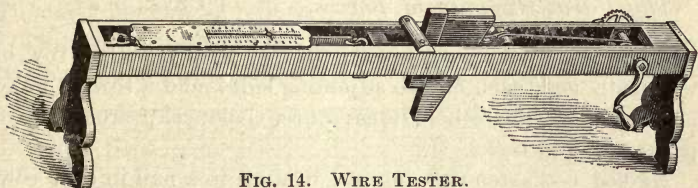


FIG. 14. WIRE TESTER.

Conclusions. — Compute the tensile strength of each wire in kilograms per square centimeter of cross section.

Is the breaking weight directly proportional to the area of cross section?

Suggested Experiments. — Test the breaking weight of iron wire and compare it with that of brass of the same cross section. Do the same for copper wire and different kinds of thread.

Can you determine how much a copper wire will stretch before it will break?

EXPERIMENT 7

To determine the Conditions of Equilibrium between Three Concurrent Forces acting in the Same Plane. The Parallelogram of Forces. El. of Phys., p. 44

Apparatus.—A board about two feet square with a row of wire nails near each of two adjoining sides, and a row of holes near each of the other sides; three balances; cross-section paper; thumb tacks.

Method.—Fasten the ring of a balance to a nail in each row, and pull the third in any desired direction. Fasten it in that position by means of a wooden or metal pin pushed into a hole. Pin the cross-section paper to the board so that the intersection of two heavy cross lines comes directly beneath the common point to which the balances are fastened. Make a pencil point on the paper directly under the connecting point of the three cords joining the balances. Take a reading of the three balances and mark

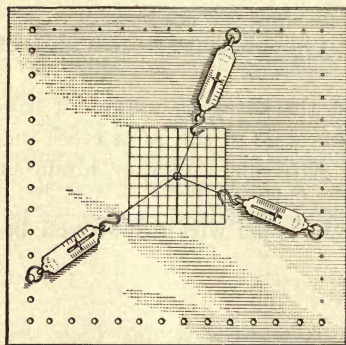


FIG. 15.

the points to which they are attached. Remove the balances and draw lines from the common point to the points of support. Lay off on these lines distances that are proportional to the readings taken. Complete the parallelogram on any two lines as sides and draw the resulting diagonal.

Conclusion. — How does the resultant compare in length and direction with the third force?

Any force that is opposite in direction and equal in intensity to the resultant of two forces is called an *equilibrant*.

Suggestion. — The use of cross-section paper makes it convenient to make a study of the relative values of the rectangular components of three forces that are in equilibrium in one plane. This may be done as follows: —

Through A , the point of application of the three forces, draw two heavy lines at a right angle to each other along the section

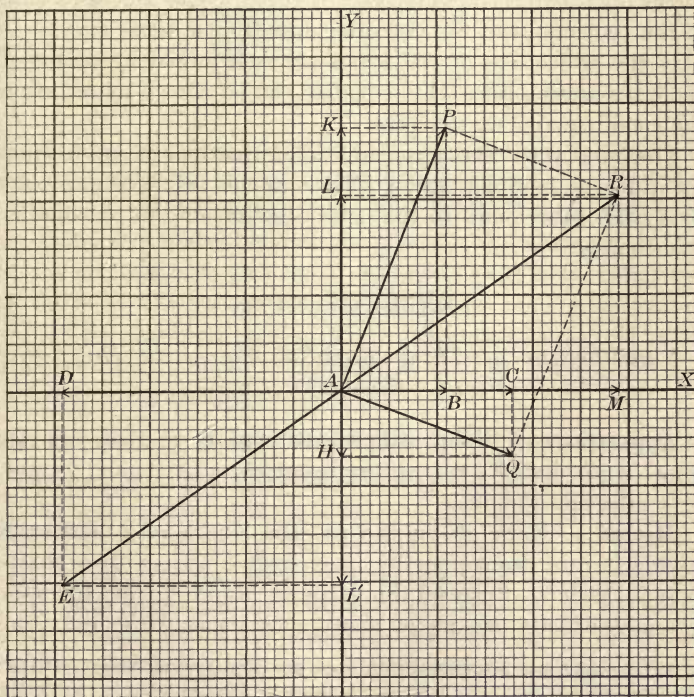


FIG. 16.

lines. Call these the axes X and Y . By projecting the forces upon these axes it will be seen: —

(a) That the projection of R on the axis of X is equal to the sum of the projections of P and Q on that axis; *i.e.* $AM = AB + AC$.

(b) That the projection of R on Y is equal to the difference of the projections of P and Q on that axis; *i.e.* $AL = AK - AH$.

(c) That the projections of E on X and Y are equal to the projections of R on the same axis but in the opposite direction.

(d) That, in general, when three concurrent forces acting in one plane are in equilibrium, the projection of any one of these forces upon two rectangular axes is equal to the algebraic sum of the projections of the two other forces upon these axes.

If the projections of the forces are determined by means of the cross-section lines, this equality can be shown by counting the small squares on the axes.

The pupil should make several determinations of equilibrium for different readings and positions of the balances and then apply the data found to the determination of the rectangular coördinates.

EXPERIMENT 8

Equilibrium of Three Parallel Forces in the Same Plane. El. of Phys., p. 47

Apparatus. — A light, stiff wooden rod more than a meter long; a meter stick; two spring balances; a two-pound weight, or a kilogram weight.¹

Method. — Mark off on the rod the length of a meter and divide it into decimeters by cross lines drawn with a sharp-pointed pencil. Suspend the balances A and B from the nails C and D exactly one meter apart, and suspend the rod from

¹ The weight may be greater, if desired, provided it is somewhat less than the total amount that each balance can measure, and can be supported by the wooden rod without much bending.

the balances by means of loops of cord at the points E and F , one meter apart. Take a reading of each balance. These readings are due to the weight of the rod and are called the "zero readings." They do not enter into the final results,

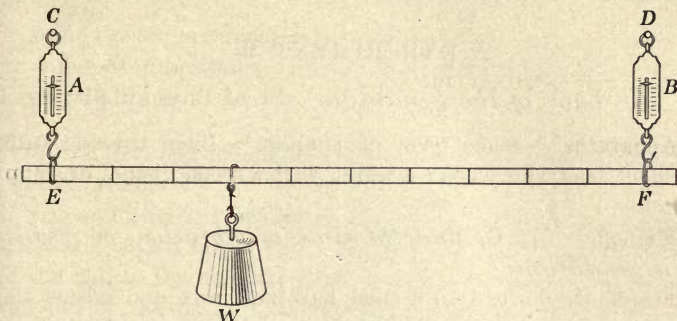


FIG. 17.

which must be corrected by subtracting from each reading the zero reading of the balance on which it is taken.

Suspend the weight W by a loop on the rod at the first mark, directly under balance A . Read both balances. Move W one decimeter to the right and again read both balances. Move W to the second decimeter division and read again. Repeat the readings, moving W one decimeter each time until it hangs directly under the balance B .

Tabulate the readings as follows:—

Distance from E	Reading of A	Reading of B	Distance from F
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Conclusions.—The meaning of the results given in the table can be best seen by making a curve which shall have the distance EF laid off along the horizontal axis and the pull on each balance for the different positions of W on the vertical axis. The curves for both balances can be made on the same sheet of paper, and a comparison of the two will aid in understanding how the pull of W is distributed to A and B according to its position on EF .

Suggestions.—State the relation between the sum of the forces acting in one direction and the force acting in the opposite direction. State the relation between the outside forces and their respective distances from the force between them.

EXPERIMENT 9

Laws of the Pendulum. El. of Phys., p. 81

Apparatus.—Some form of support¹; linen thread; balls of steel, lead, and wood; a watch with a second hand, or a stop watch.

Method.—(a) *To find the time of vibration, or period, of a pendulum.*

Fasten the thread to a steel ball with wax and adjust the thread to any convenient length, two or three feet, for example.

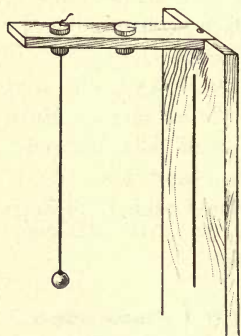


FIG. 18.

Set up a board behind the pendulum and draw a vertical chalk mark exactly behind the thread when it is at rest (Fig. 18). Draw the bob aside about 10 cm. and let it swing. Let one pupil count the vibrations aloud just as the thread passes the chalk line. Count the passages as follows: 3-2-1-go-1-2-3, and so on. This gives the second pupil who is taking the time a fair warning of the "go" when the time is to begin. Take the time of 50 or 100 vibrations, the observer giving a sharp "go" at the 100th swing, and the timekeeper reading the minutes and seconds and estimating the tenths of a second. Make three experiments and take the average of the three times as the true time.

¹ Bore holes in a narrow board and fit corks to the holes. Cut slits half-way through the corks with a sharp knife and slip the suspending threads into the slits. The friction will hold the thread in place.

Divide the time by the number of vibrations to find the period.

(b) *To find whether the amplitude affects the period or not.*

Make the same experiment with the same pendulum swung at different amplitudes. Make one experiment with a very large amplitude.

(c) *To find out whether the mass of the bob changes the period or not.*

Suspend a second pendulum of the same length as the first, but made with a larger ball. To find the length add the radius of the ball to the distance between the bottom of the cork and the top of the ball. Compare the times of vibration of the two.

(d) *To find the relation between the lengths of two pendulums when their periods are as 1 : 2.*

Find the period of a pendulum having as great a length as the apparatus will allow. Measure from the center of the ball to the point of support. Suspend a second pendulum like the first and shorten it until it vibrates twice while the first pendulum is vibrating once. Measure its length and compare the two.

Conclusions.—Does a small change in amplitude change the period? Does a large change in amplitude change the period? Explain. Does a change in the mass of the bob change the period? Do the results of (d) verify the law?

Suggestions.—Put your values of t and l in the formula

$t = 2\pi\sqrt{\frac{l}{g}}$ and find the value of g . Make a graph—a curve—that shall show the relation between the lengths and periods of simple pendulums.

EXPERIMENT 10

The Moments of Forces. El. of Phys., p. 88

Apparatus.—Three spring balances; two weights; a very stiff wooden rod more than a meter long; a meter stick; a level.

Method.—Suspend two of the balances by cords from hooks one meter apart, and suspend the third between them, as in Fig. 19. Take the reading of each balance and record it as the zero reading.

Weigh the rod. Suspend the rod from the three balances by cords as shown, so that it shall be horizontal. Suspend

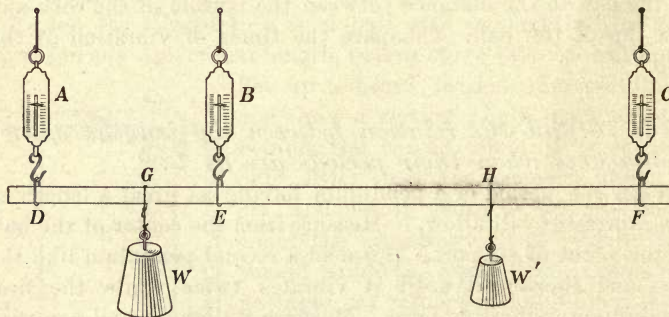


FIG. 19.

the two weights from the rod at convenient points, as at G and H , and so adjust the cords supporting the balances that the rod shall be horizontal. Assume that the forces tend to turn the rod about the point E , or that E is the center of moments. Consider that the weight of the rod itself is applied at its middle point. Compute the moment of each force, and determine whether it tends to turn the rod around the point E in a clockwise or a counter-clockwise direction. Make a computation of the moments of the forces and whether they tend to produce clockwise or counter-clockwise

rotation, taking, in turn, each of the points D , G , H , and F as the center of moments. Do the same, taking any other point K as the center of moments.

Conclusion. — How does the sum of the readings of the balances compare with the sum of the suspended weights? How does the sum of the moments that tend to produce clockwise rotation compare with the sum of those that tend to produce counter-clockwise rotation? Does it make any difference in this comparison what point you take as the center of moments?

Suggestions. — Explain in your notes how this experiment illustrates the different classes of levers. Make such changes in the apparatus as are necessary for the purpose, and test the law for each.

EXPERIMENT 11

To determine whether the Point of Application of the Weight of a Lever is in the Same Position as its Center of Gravity. El. of Phys., p. 88

Apparatus. — A straight wooden bar about two feet long; a wooden block; a weight; triangular fulcrum; try-square.

Method. — Make a saw cut A a quarter of an inch deep near one end of the bar and screw the block B to the other end. Place the triangular fulcrum F on the table and balance the bar upon it. This will be more easily done if the fulcrum edge of the block is planed off until it is about

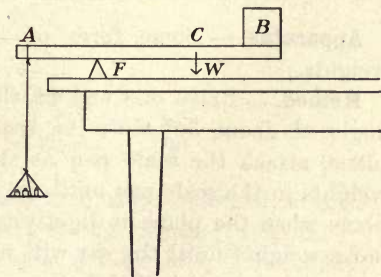


FIG. 20.

one eighth of an inch wide. When the bar is exactly balanced, mark a point, C , directly above the middle of the fulcrum edge and draw a fine pencil mark across the bar, using the try-

square to get it perpendicular to the side. Bring the fulcrum near one side of the table. Suspend the weight from the bar by means of a cord in the saw cut near the end, and balance the bar and weight as shown (Fig. 20).

Conclusion. — From the data which you have found determine the moment of the weight, taking the position of the fulcrum as the center of moments.

Determine also how far from the fulcrum the weight of the bar and block must be applied so that its moment may be equal to the moment of the suspended weight.

How does this distance compare with the distance of the center of gravity of the bar and block from the fulcrum?

Where may you consider the weight of a body to be applied?

Suggestions. — From the data that you have found prove that this is a lever of the first class.

Compute the pressure applied at the fulcrum.

EXPERIMENT 12

The Inclined Plane. El. of Phys., p. 96

Apparatus. — Some form of inclined plane; small car; weights.

Method. — Raise one end of the plane until it makes an angle of about 30° with the base. Place the car upon the plane, attach the scale pan as shown in Fig. 21, and place weights in the scale pan until the car will move slowly up the plane when the plane is lightly tapped with the finger. Remove weights until the car will move slowly down the plane when it is tapped. Weigh the scale pan and add its weight to that of its contents in each case. Take half the sum of the two weights as the true weight when the car is at rest. Take the weight of the car and its contents as the weight of the load. Repeat at a larger angle.

Conclusions. — Substitute your results in formula 35, namely, $P:W = H:L$, and find the percentage of difference between your value of P and that required by formula 35.

Calculate the work necessary to move the car along the plane from one point to another. Calculate also the work

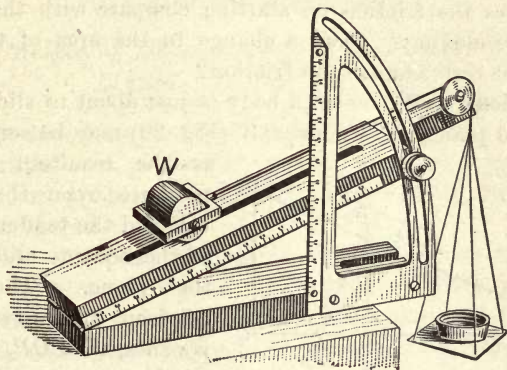


FIG. 21.

necessary to lift the car vertically through the distance measuring the difference in level of the two points. How do these two amounts of work compare?

EXPERIMENT 13

Friction. El. of Phys., p. 100

Apparatus. — A block of wood with sides of equal smoothness; a smooth hardwood board; spring balance; weights.

Method. — Place the board upon a table and, if necessary, block it up until it is level. Place the block resting on its wide face upon the board and put a 1-kg. weight upon it. Attach the block to the spring balance and pull it slowly over the board. Read the scale just before the block starts and while it is moving uniformly. Do this several times and note

the readings. Change the load and repeat. Make the experiment again, turning the block upon its narrow side.

Conclusions. — Take the average of each set of readings and determine the relation between the load and the friction of the block.

How does the friction on starting compare with that after the body is moving? Does a change in the area of the side on which it rests change the friction?

Suggestions. — Whenever a body is just about to slide down an inclined plane, the weight OW (Fig. 22) may be considered

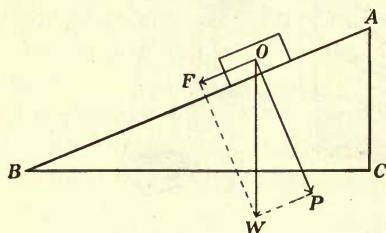


FIG. 22

as the resultant of the pressure upon the plane OP , and the tendency, OF , of the body to slide down the plane. The ratio between these two components, $OF:OP$, is, from similar triangles, the same as that of $AC:CB$. If the plane is hinged at B

and the end C raised until the body begins to slide, then a measurement of AC and BC will give the coefficient of friction; that is, $f = \frac{AC}{CB}$. Find the coefficient of friction by this

method. The ratio $\frac{AC}{CB} = \tan ABC$. Hence, we may say that the coefficient of friction between a body and a plane surface is equal to the tangent of the angle between the surface and a horizontal plane when the body begins to slide downward.

EXPERIMENT 14

The Principle of Archimedes.—The Lifting Effect of a Liquid. El. of Phys., p. 128

(a) *Bodies heavier than water.*

Apparatus. — A piece of aluminum¹ of some regular shape, cylinder or prism; an overflow can; beaker; balance and weights; thread.

Method. — Suspend the metal block from one arm of the balance by a strong thread and weigh it. Pour water into the overflow can until it flows out the spout into the beaker. When all has run out that will, throw out the water and dry the beaker. Carefully lower the metal into the water in the overflow can and catch the displaced water in the beaker. Find the weight of the metal when it is submerged. Weigh the beaker and water. Empty the beaker and dry it and weigh again. Tabulate your results as follows:—

Weight of metal in air		— grams
Weight of metal in water		— grams
Weight of beaker and displaced water		— grams
Weight of beaker alone		— grams

Find the relation between the loss of weight of the metal and the weight of the displaced water.

Conclusions. — State the Principle of Archimedes as applied to bodies heavier than water.

(b) *Bodies lighter than water.*

Apparatus. — The same as in (a) except that the aluminum

¹ Aluminum is suggested as a good metal for this experiment on account of its lightness.

is replaced by a hardwood block that has been paraffined or coated with liquid filler.

Method. — Weigh the block and the empty beaker. Proceed with the overflow can as in (a). Fasten a thread to the block and carefully lower it upon the surface of the water. Weigh the displaced water. Tabulate your results as follows:—

Weight of block	— grams
Weight of displaced water	— grams

Find the relation between these two weights.

Conclusions. — State the Principle of Archimedes as applied to bodies lighter than water.

Suggestion. — Shape a sheet of tin so that it will float. Explain why it floats.

EXPERIMENT 15

To determine the Specific Gravity of Solids heavier than Water. El. of Phys., p. 133

Apparatus. — A pair of balances with one arm provided with a suspension hook; beaker of water; thread; the solids to be tested, such as iron, granite, sandstone, aluminum, etc.

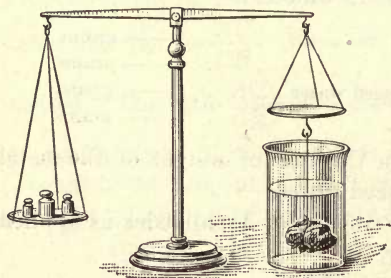


FIG. 23.

Method. — Weigh the solid in air, suspending it from the hook with a thread. Fill the beaker two thirds full of water, distilled if possible and having a temperature as near 4° C. as possible. Weigh the solid again while it is submerged in the water

(Fig. 23), being careful that no bubbles of air are attached to the solid. Make a record of the weights as follows:—

SUBSTANCE	WEIGHT IN AIR	WEIGHT IN WATER
Iron		
Granite		
Sandstone		

Conclusions. — Compute the specific gravity from the expression

$$\text{Sp. gr.} = \frac{\text{Weight of solid in air}}{\text{Loss of weight in water}}.$$

Suggestions. — Why should distilled water be used? Why should it be as near 4° C. as possible? How do your determinations of specific gravity compare with those of the same substances as given in the table? What parts of the experiment require especial care? Find out whether a certain “silver” spoon is solid silver or plated.

EXPERIMENT 16

To determine the Specific Gravity of a Body lighter than Water. El. of Phys., p. 133

Apparatus. — A cake of wax; aluminum (or other metal) sinker; beaker of water; balance and weights.

Method. — Weigh the wax in the air. Call this weight W . Weigh the sinker in the water. Call this weight S . Tie the wax and sinker together and weigh them in water. Call this weight W'' . Compute the specific gravity of the wax from the expression

$$\text{Sp. gr.} = \frac{W}{W + (S - W'')}.$$

Conclusion. — The reason for the above equation may be illustrated as follows: Assume, for example, that a piece of paraffin weighs 7.12 g. (W) in air, that an aluminum sinker

weighs 6.28 g. (*S*) in water, and that the two when tied together and weighed in water weigh 5.4 g. (*W''*). Now it is evident that the paraffin displaces enough water, not only to overcome its own weight, but to lift 6.28 g. — 5.4 g. = 0.88 g. of the weight of the aluminum sinker. That is, the paraffin displaces 7.12 g. + 0.88 g. = 8 g. of water. Hence the specific gravity of the paraffin = $7.12 \div 8 = 0.89$.

State the Principle of Archimedes, and show how it applies in this experiment.

Suggestions. — Find the specific gravity of paraffin, cork, and a tennis ball.

EXPERIMENT 17

To determine the Specific Gravity of Liquids. El. of Phys., p. 134

(a) *With the specific gravity flask.*

Apparatus. — A specific gravity flask, made of a bottle with an ordinary glass stopper, or better with a glass stopper having a small hole through it lengthwise; balance and weights; water; and the liquid, the specific gravity of which is to be found, — alcohol, for example.

Method. — Weigh the flask empty. Fill it with water, being careful that no air bubbles remain inside when the stopper is put in. Wipe the outside of the flask dry and weigh it again. Pour out the water and dry the flask. Fill it with the alcohol, taking the same precautions as before, and weigh again.

Tabulate your results as follows: —

Weight of empty flask	— grams
Weight of flask and water	— grams
Weight of flask and alcohol	— grams

Find the weight of the water and of the alcohol and compute the specific gravity of the alcohol.

Conclusion. — How does your result compare with the specific gravity of absolute alcohol, which is given in the Smithsonian Physical Tables as 0.789 at 20° C. ?

(b) *With the specific gravity bulb.*

Apparatus. — A specific gravity bulb (see Suggestions below); balance and weights; beaker; alcohol; water.

Method. — Weigh the bulb in air, then in water, and then in the alcohol. Compute the specific gravity of the alcohol from the equation,

$$\text{Sp. gr.} = \frac{\text{Loss of weight in alcohol}}{\text{Loss of weight in water}}.$$

Why is this equation correct ?

Suggestions. — For liquids that do not act upon it a piece of aluminum makes a good specific gravity bulb. A glass bulb can be made as follows: Fuse the end of a glass tube a half inch or more in diameter in the Bunsen flame until it closes. Let the tube cool and then heat it in the point of the flame at a distance of two inches from the closed end. Draw the tube down to a diameter of not more than a quarter of an inch and again let it cool. Pour a number of shot into the bulb and again heat at the narrow part. Separate the bulb and draw the small end into the form of a hook as shown in Fig. 24.



FIG. 24.

(c) *With Hare's apparatus.*

Apparatus. — The piece of apparatus shown in Fig. 25. *A* and *B* are glass tubes joined at the upper ends to the branches of a T or Y tube. The other end of the Y is connected to a rubber tube *R*. Under the lower end of each is a glass dish, one to contain water and the other alcohol. *C* is a clamp, and *M* a meter stick between the tubes.

Method. — Draw the air from the tube *R* by suction, being careful not to bring the column of liquid in either glass tube

too near the top. Close *R* with the clamp and take readings both of the height of liquid in the tubes and of that in the glass dishes at the lower ends. Loosen the clamp and let a little air into the tube *R*. Take a second set of readings. Remove the clamp from the tube and take readings of the height to which the liquid stands in each tube due to capillarity.

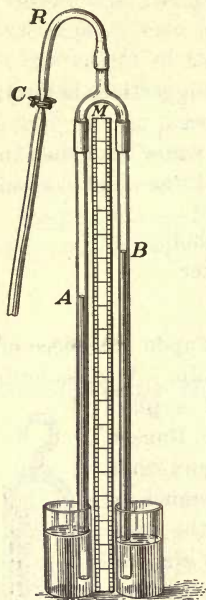


FIG. 25.

Conclusion. — Compute the specific gravity of the alcohol by comparing the relative heights of the water column and the alcohol column.

Suggestions. — Bend a glass tube, one fourth of an inch or so in internal diameter and about six feet long, into a U form with the branches an inch and a half apart. Fasten them to a board and fasten a meter stick to the board between the branches of the U. Pour mercury into one branch of the tube until it stands at least two inches high in each branch.

Pour distilled water into one branch until it stands about twenty inches higher than the top of the mercury in the other branch, as in Fig. 26.

Read the height of the mercury columns in both branches and the height of the water column. Compute the specific gravity of mercury from the data found.

Find the specific gravity of alcohol by pouring alcohol on the top of the mercury column until the mercury column is at the same height in both branches. Read the heights of the columns and compute the specific gravity.

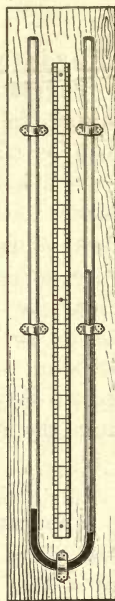


FIG. 26.

Gasoline can be used in the place of alcohol if preferred, but great care must be taken that no fire comes near it, as the vapor is very inflammable.

A satisfactory experiment is to make a 2% solution of salt in water and find its specific gravity. Then add enough salt to make a 4% solution, and so on, adding salt enough to make the solution 2% greater each time. Make a curve to show the relation between the percentage of salt in solution and the density.

EXPERIMENT 18

To determine the Specific Gravity of Air. El. of Phys.,
p. 140

Apparatus. — A glass bottle of three or four liters capacity; a rubber stopper with one hole; two short glass tubes; one short and one long rubber tube; a clamp; air pump; balance and weights.

Method. — Weigh the bottle when it is filled with air, and when the stopper, one glass tube, short rubber tube, and clamp are in place.

Pump the air from the bottle, close the clamp, and weigh again.

Thrust the rubber tube under water and open the clamp. Push the bottle down until the water stands at the same height inside and outside. Then close the clamp, wipe dry the outside of the bottle and fittings, and weigh the bottle, fittings, and the water that has taken the place of the air that was drawn out by the pump.

Conclusion. — Call the first weight W , the second W' , and the third W'' . Compute the specific gravity of the air from the formula

$$\text{Sp. gr.} = \frac{W - W'}{W'' - W'}$$

Show why this will give the specific gravity. Great care should be exercised in taking the three weights exactly. Why? Can you expect to get very accurate results by this method?

Suggestion. — A satisfactory demonstration of the weight of air may be made as follows: Weigh an incandescent lamp bulb—a new one is best, though one with a broken filament will answer, provided no leakage has taken place. Weigh this as carefully as possible. With a blowpipe direct the tip of a small pointed flame from a Bunsen burner upon the side of the glass (Fig. 27). As soon as it gets soft a small hole will be blown in the side by the pressure of the atmosphere and as it is from without inward no part of the lamp will be lost. Weigh the lamp carefully again. Fill the bulb entirely full of water, remove all water from the outside, and weigh for the third time.

From the data thus obtained find the specific gravity of the air. If your data show that there was some gas present in the lamp, compute the amount present.

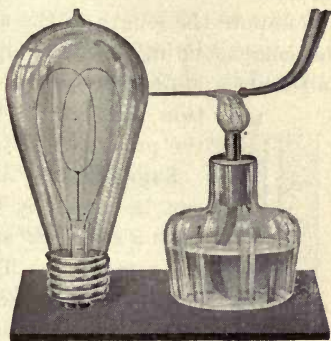


FIG. 27.

EXPERIMENT 19

To find the Relation between the Pressure upon a Given Mass of Air and the Resultant Volume. Boyle's Law.
El. of Phys., p. 150

Apparatus. — The usual Boyle's law apparatus (or see Suggestion below); mercury; barometer.

Method. — Determine the pressure of the atmosphere by reading the barometer. Set up the apparatus so that the scale is vertical. Adjust the positions of the arms until the level of the mercury is the same in both. Take the reading both of the mercury surfaces and of the top of the air column, and com-

pute the length of the column of air. Raise the open tube and take a reading of the top of the two mercury columns. Repeat this until the open tube is raised as high as is convenient. Take a reading of the barometer after these readings are finished and compare it with the reading taken at the beginning.

Conclusion. — The closed end of the apparatus should be of uniform diameter, hence the volume of the inclosed air will be proportional to the length above the end of the mercury column.

Compute the length of the air column in the closed tube and the corresponding pressure upon it for each set of readings, and write a statement of the law that shall express the relation between the volume of a given quantity and the pressure upon it.

Suggestion. — A convenient form of apparatus can be made by taking a graduated gas burette with a stopcock at one end for the short arm of the apparatus. This makes it easy to adjust the amount of air used at the beginning, and to find the initial volume. A straight piece of glass tubing can be connected by a T tube and two short rubber tubes to the lower end of the burette, and by mounting this on a board stand as shown in Fig. 28, and fixing a meter stick in place in a vertical direction, the apparatus is completed.

Slip a short rubber tube and clamp on the end of the T. Pour mercury in the long tube and bring it to a level in both tubes by the burette valve. Regulate the amount of air in the burette by the T clamp. Take one set of readings by pouring mercury into the long arm a little at a time, and a second set by drawing mercury from the T clamp a little at a time. Make a graph showing the relation between pressure and volume.

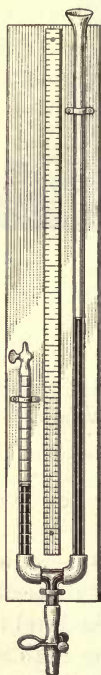


FIG. 28.

EXPERIMENT 20

To measure Gas Pressure by the Use of a Manometer.
El. of Phys., p. 151

Apparatus. — An open manometer. This can be made from a 6-ft. piece of small tubing bent and mounted on a support as shown in Fig. 29.

Method. — Pour water into the tube at the end *A* until it stands at about the point *C* in both tubes. Couple the end *B*, which should be bent away from the support, to the gas supply by a rubber tube and turn on the gas. Read the water columns in both tubes.

Conclusions. — Compute the pressure of the gas per square centimeter and per square inch.

Suggestion. — Replace the water with mercury, and measure the pressure in a football by coupling it both to a force pump and to the manometer tube at *B* by a T tube. If the manometer tube is not long enough, make another like that in Fig. 30, using a strong bottle for a mercury tank.

The height of the mercury in the tube above that in the bottle is a measure of the pressure.

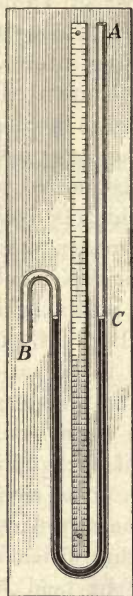


FIG. 29.

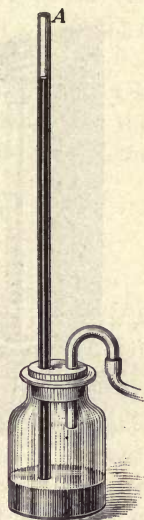


FIG. 30.

EXPERIMENT 21

To determine the Velocity of Sound in the Laboratory and to measure the Wave Length of Sound. El. of Phys., p. 178

Apparatus.—A tuning fork of a known number of vibrations ; a cork hammer; resonance tube and support, as shown in Fig. 31. This form of tube is about 10 mm. in internal

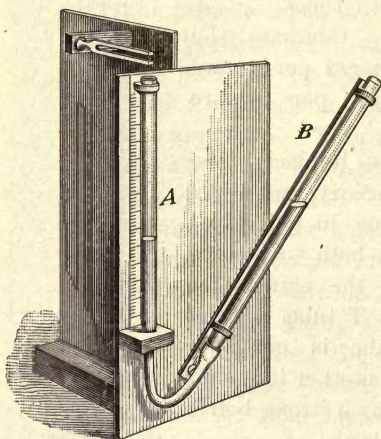


FIG. 31.

diameter and is drawn out and connected to a flexible rubber tube at the lower end. This is in turn connected to a second tube which is fixed to a movable wooden arm. The arm moves with so much friction that it will stay in any position. Back of the tube *A* there is a scale graduated in millimeters, the zero of the scale being the position of the fork when at rest. At a right angle to the main vertical support is another which is

so arranged that forks of various lengths may be held in position.

Method.—Place the tuning fork in the support and pour water into the tube until it is at least half full. Move *B* from the vertical position until the air column in *A* is of the right length to give the maximum resonance to the fork. This

position can be found accurately by moving the arm *B* back and forth through the required position.

Conclusions. — How far must the pulse of the sound wave given out by the fork go during half a vibration of the fork?

What is the relation of the wave length of the fork and the length of the air column? Compute the wave length of the fork.

For accurate work a correction must be made for the diameter of the tube. This practically amounts to adding the radius of the tube to its length.

Compute the velocity of sound by the formula $v = 4 N(l + r)$. Explain this formula.

For comparison, compute the velocity of sound by the formula $v = 332.4 \sqrt{1 + 0.003665 t}$, or $v = 1090.5 \sqrt{1 + 0.003665 t}$. How do the results agree?

Suggestions. — Use a fork of such a wave length that you can find two places for maximum resonance. Determine the relation between the wave length and the distance between the two points.

EXPERIMENT 22

To determine the Number of Vibrations of a Tuning Fork. El. of Phys., p. 184

Apparatus. — A cork hammer or bass viol bow; the special apparatus shown in Fig. 32. This consists of a rectangular board with a groove $\frac{1}{8}$ inch deep in which a long piece of glass, *B*, slides easily. At *C* is a support for the tuning fork. On *D* a movable arm *A* is clamped to support the pendulum.

To the lower side of the pendulum is fastened a flexible bristle, the end of which bears lightly upon the glass. Near the end of the prong of the tuning fork is a somewhat stiffer bristle, so fastened to the prong by a piece of wax that it lightly touches the glass at an inclination to its surface.

Method. — Adjust the support of the pendulum until it beats $\frac{1}{4}$ seconds. This must be accurately determined by repeated trials. Clean the glass plate and lightly smoke its surface by

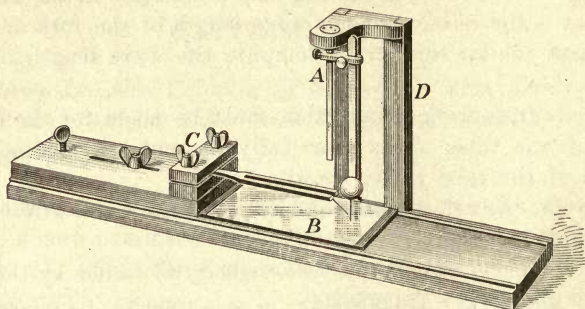


FIG. 32.

holding it over the flame of a candle, or of a piece of burning camphor (see Suggestion below). Fix the fork in such a position that the two bristles are very near to each other in the line of motion of the glass plate. Put both the fork and the pendulum in vibration and pull the glass plate along in the groove. Remove the plate and count the number of vibrations of the fork that correspond to the distance between two marks of the pendulum, taking the middle of each mark of the latter.

Conclusion. — How many vibrations does the fork make for each vibration of the pendulum? How many per second? What is the pitch of the fork?

Suggestion. — The following is a much cleaner method of taking the trace. Cover the glass plate with a thin coat of kerosene, or vaseline, by rubbing the plate with a cloth on which you have put a few drops of the oil. Then sift a little flour or cornstarch on the plate through a sieve made by stretching a piece of thin muslin between two embroidery hoops. Jar the plate slightly to remove the loose flour, and there will be left a coating that will give a good trace.

EXPERIMENT 23

Testing the Fixed Points of a Thermometer. El. of
Phys., p. 211

(a) *To test the freezing point.*

Apparatus.—Thermometer; a dish, perforated at the bottom, such as a small flowerpot or a funnel; cracked ice or snow.

Method.—Place the bulb of the thermometer in the dish and surround it completely with cracked ice, covering the stem almost to the freezing point, 0° C. or 32° F. Let it stand in the melting ice until there is no change in the position of the top of the mercury column, and then take a reading to the tenth of a degree.

Conclusion.—Why should the ice be melting when the reading is taken? Make a record of the reading of the thermometer and observe whether the error is plus or minus.

(b) *To test the boiling point of a thermometer.*

Apparatus.—A boiler or a large Florence flask; a stopper with two holes; thermometer to be tested; a standard thermometer; Bunsen burner and tripod; barometer.

Method.—Compare the reading of the thermometer to be tested with a standard thermometer. Put such a quantity of water in the flask that when the bulb of the thermometer, which has been pushed through one hole in the stopper, is about an inch above the water, the boiling point, 100° C. or 212° F., shall be just above the stopper. The other hole of the stopper should be left open for the free escape of the steam.

Place the flask on the tripod and apply the heat of the

Bunsen burner. When the steam has been coming from the flask for about five minutes and there is no further change in the mercury column, take a reading of the boiling point. Note the reading of the barometer. Remove the thermometer from the flask and take simultaneous readings of the temperature of the air with both the thermometer used in the experiment and the standard thermometer.

Conclusions.—From the reading of the boiling point and that of the freezing point determine what correction per degree must be made for accurate work. As the barometric pressure affects the temperature of the boiling point, it may be necessary to make a correction in the reading on that account, though the change will probably be very slight. In order that the boiling point shall be 100°C . or 212°F ., the barometric pressure must be 760 mm. A change of 27 mm. in the reading of the barometer when the temperature is near 100°C . causes a change of 1° in the centigrade reading, and a change of 15 mm. causes a change of 1° in the Fahrenheit reading.

How soon after a thermometer has been raised to 100°C . would you use it for accurate work at ordinary air temperatures?

Suggestion.—The fact that there is a rise in temperature with an increase of pressure can be shown by making use of a boiler like that shown in Fig. 33. The pressure can be increased by partly stopping up the exit of the steam pipe. The amount of the pressure can be found by reading the difference in the height of the mercury in the sides of the U tube *m*.

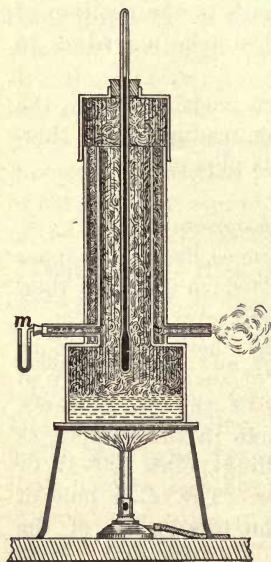


FIG. 33.

EXPERIMENT 24

To find the Coefficient of Linear Expansion of Solids.

El. of Phys., p. 228

Apparatus.—Linear expansion apparatus (Fig. 34); boiler or flask; delivery tube; Bunsen burner; meter scale; a brass, iron, or aluminum tube to be tested.

Method.—Pass the end of the screw hook which forms the fixed point *A* (Fig. 34) through a hole near one end of the metal tube, and adjust the short end of the lever in a hole in

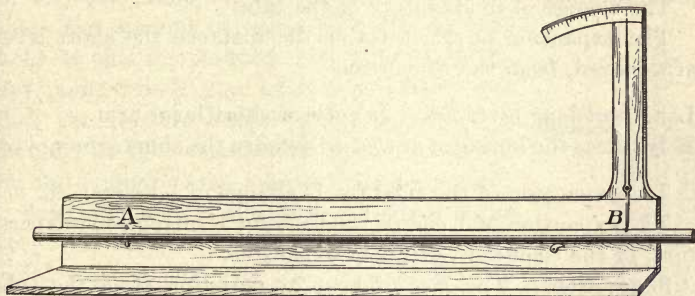


FIG. 34.

the upper side of the tube at *B*. Measure accurately the length of the tube between *A* and *B*, and the length of each lever arm.

Let the apparatus stand for some time at the temperature of the room, and then take a reading of the long lever arm. Call this reading the zero reading. Take a reading of a thermometer near the apparatus.

Fill the boiler about a third full of water, connect with the delivery tube, leaving the end of the tube open, and heat over a Bunsen burner. When the water boils, connect the delivery tube to the metal tube, being careful not to disturb the position

of the pointer. When steam has been coming freely from the tube for some minutes and there is no further movement of the pointer, take a reading of the position of the pointer. Record your results as follows:—

Initial length of tube	.	.	.	.	.	— cm.
Length of long lever arm	.	.	.	.	.	— cm.
Length of short lever arm	.	.	.	.	.	— cm.
Initial reading of long lever arm	.	.	.	.	.	— cm.
Final reading of long lever arm	.	.	.	.	.	— cm.
Initial temperature	.	.	.	.	.	—° C.
Final temperature	.	.	.	.	.	100° C.

Conclusions.— From the results obtained compute:—

The change of temperature of the tube.

The expansion of the tube, or the distance the short lever arm moved, from the proportion

Length of long lever arm : Length of short lever arm
= Distance the long arm moved : Distance the short arm moved.

The expansion of the tube for 1° change of temperature.

The expansion of 1 cm. of the tube for 1° change of temperature, or the coefficient of linear expansion.

Suggestion.— The loss of heat by radiation from the tube can be kept down by surrounding the greater part of the tube with a glass tube.

EXPERIMENT 25

To determine the Dew-Point and Relative Humidity.

El. of Phys., pp. 239–240

Apparatus.— A small nickel-plated calorimeter; ice water; thick pad of woolen or felt; thermometer.

Method.— Place the felt pad upon a table and put the calorimeter upon it. Pour water, at the room temperature, into the calorimeter until it is half full. Insert the thermometer

and pour ice water into the calorimeter, stirring constantly with the thermometer. Take the temperature as soon as mist is seen to form on the polished surface of the calorimeter. Stop adding ice water and watch the surface to note the disappearance of the mist. Take the temperature at the time it disappears.

Conclusion. — Compute the dew-point by averaging the two temperatures.

This point found, it will be possible to find the relative humidity if we know the number of grams of water vapor that saturated air contains per cubic meter at different temperatures. This is shown in the table on page 239 of the Elements of Physics. Find the temperature of the air. Take from the table the amount of vapor that the air will hold at this temperature and at that of the dew-point which you have just found, and find the relative humidity by dividing the amount at the temperature of the dew-point by the amount at the temperature of the air.

Suggestions. — A simple form of apparatus (Fig. 35) for the determination of the dew-point can be made as follows: Blacken an inch of the lower end of a large test tube by painting it with asphalt varnish. Pour a little ether into the tube. Insert a thermometer and take its temperature. Insert a glass tube into the test tube and connect it to a rubber tube two feet long, having a glass mouthpiece at the other end. Blow through this tube gently and notice that as the ether evaporates more rapidly its temperature falls. Keep blowing until a mist forms at the lower part of the tube. Take the temperature as soon as the mist begins to form. Stop blowing and take the temperature again just as the mist disappears. Repeat and take the average of several trials.

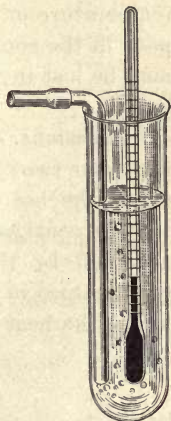


FIG. 35.

EXPERIMENT 26

To find the Law of Heat Exchange by the Method of Mixtures. El. of Phys., p. 248

Apparatus. — Three beakers — two of the same size; balance and weights, or graduate; Bunsen burner and tripod.

Method. — Place in one of the two similar beakers 300 g. of water. Place this on the tripod and heat the water quite hot with the Bunsen burner. Pour into the other beaker 300 g. of cold water. Take the temperature of the water in both beakers and quickly pour their contents into the third. Take the temperature of the mixture. Consider this experiment preliminary, and repeat, bringing the third beaker to about the temperature of the mixture in the first experiment before you pour in the contents of the other two, so that none of the heat may be lost in warming the beaker that is to contain the mixture.

Conclusions. — Is the resulting temperature a mean between the other two? Compute the number of calories of heat given off by the hot water = (mass in grams $\times$ change in temperature in centigrade degrees); also number of calories of heat absorbed by the cold water = (mass in grams $\times$ change in temperature in centigrade degrees). What is the relation between the heat given out and the heat absorbed?

EXPERIMENT 27

To find the Specific Heat of a Solid. El. of Phys., p. 248

Apparatus. — A Bunsen burner; water boiler; copper calorimeter; thermometer; balance and weights; sheet of aluminum, the specific heat of which is to be measured; a thick felt pad.

Method. — Roll the metal sheet into an open spiral roll with about a quarter of an inch between the surfaces. Attach a

fine piece of copper wire to one corner of the roll for a handle. Weigh the roll. Weigh the empty calorimeter. Place sufficient water in the calorimeter to cover the roll, and weigh. Set the calorimeter upon the felt pad. Place the roll in the boiler and cover with water. Heat over the Bunsen burner. When the water has been boiling for some time, take the temperature of the water in the calorimeter and transfer the roll from the boiling water to the calorimeter as quickly as possible. Stir the water in the calorimeter and take its temperature near the top of the water, near the bottom, and at different points near the sides of the roll. If these readings differ, stir again and repeat, taking the highest uniform temperature as the reading.

Record your results as follows:—

Mass of metal	— g.
Mass of calorimeter	— g.
Mass of calorimeter and water	— g.
Mass of water	— g.
Temperature of water	— g.
Temperature of metal	— g.
Resulting temperature of water and metal	— g.

Conclusion.—Compute: (1) Change in temperature of water.

(2) Change in temperature of metal.

(3) Heat absorbed by water. This may be represented by the expression mts ; that is, the product of the mass in grams, the change of temperature in centigrade degrees, and the specific heat of the substance.

(4) Heat given out by the metal. This may be expressed as $m't's'$.

(5) The specific heat of the aluminum, from the equation

Heat absorbed by water = heat given out by aluminum

or $mts = m't's'$.

(6) Per cent of error, found by comparison of this specific heat with 0.214, the value given in the table, El. of Phys., p. 248.

Suggestions. — In making accurate determinations, allowance must be made for the heat absorbed by the calorimeter, which may be done by finding its *water equivalent*. This is the product of its mass in grams by its specific heat, and is added to the mass of the water as explained in El. of Phys., pp. 249, 250.

On account of its small specific heat it is better to use a copper calorimeter in these experiments than one of glass. If its surface is burnished, the loss by radiation is also less.

A convenient stirrer is made by cutting two slits in a thin sheet of copper about $1 \times 1\frac{1}{2}$ inches and slipping it on to the thermometer bulb. It will be well to test the temperature of the boiling water with a second thermometer.

EXPERIMENT 28

To determine the Heat of Fusion of Ice. El. of Phys.,
p. 249

Apparatus. — Calorimeter; ice bag of heavy cotton or canvas; thermometer; Bunsen burner; tripod; beaker; balance and weights; a mallet.

Method. — Pour into the beaker about 400 cc. of water and heat it over the Bunsen flame. Weigh the calorimeter and call the mass M . Put about 100 cc. of ice in the ice bag and break it into fine pieces with the mallet. When the water in the beaker is heated to about 80°C ., pour about 200 cc. into the calorimeter and weigh again, calling the mass M' . Read the temperature of the water in centigrade degrees and call it T . Take the crushed ice from the bag and put it into the calorimeter, being careful that the ice is dry.

Stir the water and ice with the thermometer and read the temperature, in centigrade degrees, as soon as the ice is all melted. Call this temperature T' . Weigh the calorimeter and contents, and call the mass M'' .

Conclusion. — Compute the heat of fusion of ice, *i.e.* the number of calories required to melt one gram of ice, from the following data: —

Mass of calorimeter	M
Mass of water	$(M' - M)$
Mass of ice	$(M'' - M')$
Change of temperature of water and calorimeter	$(T - T')$
Change of temperature of the water from melted ice	T'
Heat given out by hot water	$(M' - M)(T - T')$
Heat given out by the calorimeter	$M(T - T')C$

In this expression C is the specific heat of the calorimeter metal.

Heat absorbed by the ice in melting $F(M'' - M')$

In this expression F is the heat of fusion.

Heat absorbed in heating the resulting water to $T''^\circ \text{C.}$ $(M'' - M')T'$

$$\text{Hence, } F = \frac{(M' - M)(T - T') + M(T - T')C - (M'' - M')T'}{M' - M'}$$

Suggestions. — It will be well to consider the first experiment as a preliminary trial, and so to adjust the amounts of water and ice taken in the second that the final temperature will be nearly that of the room. This will make the losses due to radiation so small that they may be disregarded. If the water in the calorimeter cools too much while it is being weighed, it should be set on the tripod and again brought to the proper temperature. Aluminum is chosen for the test on account of its high specific heat. Shot can be used, but the low specific heat of lead is apt to make the result unsatisfactory.

EXPERIMENT 29

To determine the Heat of Vaporization of Water. El. of Phys., p. 250

Apparatus. — Bunsen burner and tripod; steam boiler; condensation trap; calorimeter; non-conducting pad; cracked ice; thermometer; a screen.

Method. — Fill the boiler about half full of water, place it upon the tripod, connect it with the trap and delivery tube, as in Fig. 36, and light the Bunsen flame. Set up the screen between the Bunsen flame and the calorimeter so as to keep off the radiant heat as much as possible. It will be well to cover the steam tubes with felt or cotton. Cool some water with cracked ice until it is about 15° below the temperature of the

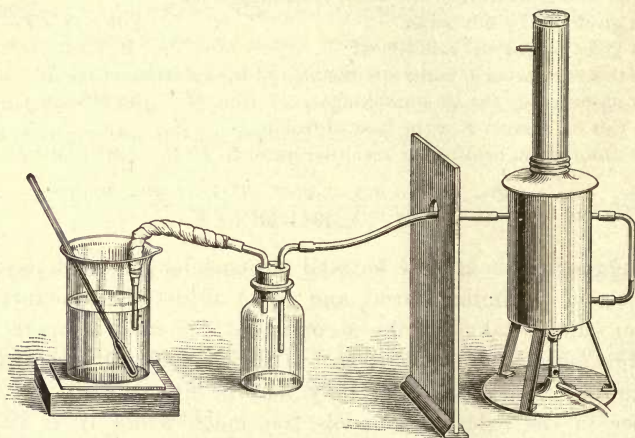


FIG. 36.

room. Weigh the calorimeter and pour it about two thirds full of the cooled water. Weigh the calorimeter with the water in it. When the steam comes freely from the delivery tube without any condensed water, take the temperature of the water in the calorimeter and place the end of the delivery tube about 2 in. below the surface of the water. Stir the water in the calorimeter with the thermometer, and when it is as much above the temperature of the room as the cooled water was below, remove the end of the delivery tube, stir the water with the thermometer, and take its highest temperature. Weigh the calorimeter and contents.

Conclusion. — Record your results as follows: —

Mass of calorimeter	_____
Mass of calorimeter and water	_____
Mass of calorimeter, water, and condensed steam	_____
Temperature of cooled water and calorimeter	_____
Final temperature of calorimeter, water, and condensed steam	_____

Compute: —

Mass of water before adding steam	_____
Mass of steam added	_____
Change in temperature of calorimeter and water	_____
Change in temperature of steam	_____
Heat absorbed by water	_____
Heat absorbed by calorimeter	_____
Heat given out in changing steam to water	_____
Heat given out by changing temperature of condensed steam	_____

From these data find the calories of heat given out by one gram of steam at 100° in condensing to water at 100° .

EXPERIMENT 30

To find the Pressure of Saturated Ether Vapor at Different Temperatures. El. of Phys., pp. 253-255

Apparatus. — Glass tubing; mercury; Bunsen burner; a tall glass beaker; metric scale; thermometer; ether.

Method. — Bend a piece of small glass tubing into the form of a U tube with one arm twice as long as the other (Fig. 37), — 15 cm. for the short arm and 30 cm. for the long arm are suitable lengths, — and close the short arm. Mark off a scale along a narrow board and wire the tube and thermometer to it. Fill the tube to within a quarter of an inch of the top of the open end with mercury, by pouring mercury into the long arm and manipulating the tube until the air passes out of the short tube and mercury takes its place. Put in ether enough to fill it completely, and so manipulate the tube as to transfer the ether to the upper end of the tube at *A*. Push an iron rod or

wire into the open end of the long arm and force out some of the mercury until it stands at the same height in both arms.

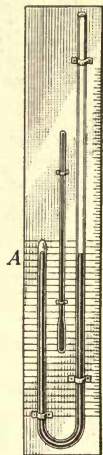


FIG. 37.

Pour water into the beaker to such a depth that it will cover the short end of the tube when it is placed in the beaker and heat it to about 35°C . (*Caution:* Be careful to have no open flame come near either the ether or its vapor, since both are very inflammable.) Lower the tube into the water carefully and note the result. The ether will probably not vaporize at that temperature. Remove the tube and add a small quantity of hot water. Insert the tube again and observe. Keep adding hot water until the ether vaporizes, being careful that this does not take place so quickly as to force the mercury from the end of the long arm. When the water is at such a temperature that the mercury will stand nearly at the top of the long arm, take a reading of the temperatures and pressure. Take frequent readings as the water

cools to such a temperature that all the vapor has liquefied.

Conclusion.—Make a graph that shall show the relation between the temperature and pressure of ether vapor.

Suggestions.—Find in this experiment the boiling point of ether.

Make the same experiment with alcohol and note the difference.

Why is the experiment difficult to make with water?

Is there a suggestion in this experiment of the pressure of superheated steam?

EXPERIMENT 31

Lines of Force in a Magnetic Field. El. of Phys., p. 265

Apparatus. — Bar and horseshoe magnets; plate of window glass; sheet of white unruled paper; wooden strips of the same thickness as the magnets; iron filings and a sieve made by stretching a piece of cheesecloth over a pair of embroidery rings.

Method. — Place a bar magnet upon the table and around it place several wooden strips to steady the glass plate. Lay over the magnet the sheet of paper and upon this place the plate of glass. Sift iron filings evenly over the plate. Jar the plate by rapping it on the edge with a lead pencil until the filings show by their position the direction of the lines of force; and by their arrangement the relative intensity of the magnetic field.

Make similar studies of the lines of force around the end of a bar magnet: in the space between the end of a long bar magnet and a short magnet placed as in (a), Fig. 38; in the space between the end of a bar magnet and a horseshoe magnet placed as in (b); and in the space between the end of a bar magnet and a piece of soft iron of the same width and thickness as the magnet, as in (c).

Conclusion. — Make drawings of the fields examined by representing the magnets by full lines, and the lines of force by fine dotted lines. Assume the direction of the lines of force to

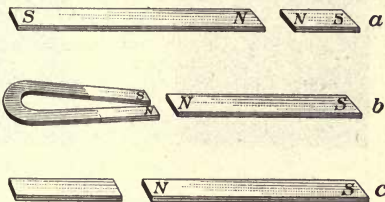


FIG. 38.

be that in which the north pole of a needle would be propelled, *i.e.* from the + pole of the magnet through the space around the magnet to the — pole, and indicate it by an arrow point on the dotted lines.

In what direction do the lines of force pass within the magnet?

State the law of mutual action in magnets and give examples of its evidence from your drawings.

Suggestion. — The best method of making permanent records of these curves is as follows: Study them until an example

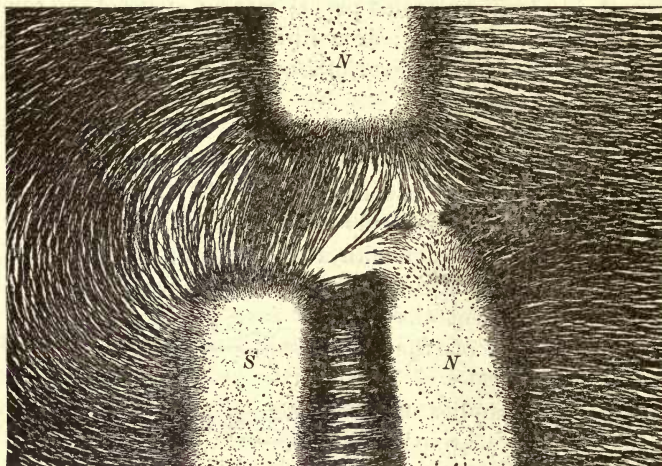


FIG. 39.

is found that is wanted. Then go into a photographic dark room and, using a photographic plate for the support, place it, film side up, on the magnet. Sift on the filings, rap the plate until they are in the right position, then expose the plate by burning a match a foot or more above the plate. Develop the plate in the usual way and thus obtain a negative from which any number of prints similar to Fig. 39 can be made.

Blue print paper can be used on which to sift the filings. When arranged satisfactorily, the paper can be exposed by

placing in the sunlight and the developing can be done in water. This, however, gives white lines on a blue ground, that is, a negative.

EXPERIMENT 32

Mapping Lines of Force in a Magnetic Field. El. of Phys.,
p. 266

The force that determines the direction in which a compass needle points is the resultant of all the magnetic forces that act upon the needle. As it is generally necessary to make magnetic experiments in the magnetic field of the earth, the effect of that field must be taken into the account. The effect of this field can be eliminated if the precaution is taken so to arrange the position of the apparatus that the magnetic needle is in the magnetic meridian at the time the reading is taken.

To map out the direction of the lines of force around a bar magnet.

Apparatus. — A bar magnet; small compass not more than half an inch in diameter; a drawing board twice as long as the magnet; a sheet of drawing paper pinned to the board.

Method. — Lay the magnet in the middle of the paper with its length parallel to one side. Place the compass at one corner of the magnet and turn the board until the needle is in the magnetic meridian. With a sharp pencil place a small dot at the + end of the needle just outside of the compass case (Fig. 40). Move the compass along until the dot is just at the

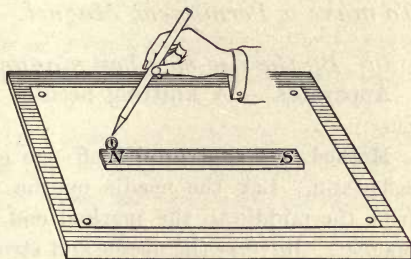


FIG. 40.

edge of the case and nearest the — end of the needle, turning the board until the needle is again in the meridian. Repeat the process until the compass is brought back to some part of the magnet. Then the curved row of dots will mark out the path of one of the lines of force of the bar magnet. Make a second curve, beginning at a short distance from the first. Repeat until the whole of the space around the magnet is mapped. Draw a figure of the magnet by passing a pencil point about it before you remove it from the paper, and mark the + and — ends.

Conclusion. — Name this drawing, Lines of Force around a Bar Magnet — Earth's Field Neutralized.

Suggestion. — Make the same experiment, placing the magnet in the east and west direction and not changing the position of the board. In this case the direction of the lines mapped out will show the influence of the earth's magnetism. Call this drawing, Lines of Force around a Bar Magnet — Earth's Field not Neutralized. Compare the two drawings and explain.

EXPERIMENT 33

To make a Permanent Magnet. El. of Phys., pp. 263–274

(a) *By the use of a bar magnet.*

Apparatus. — A knitting needle; bar magnet; small compass.

Method. — Grind or file off one end of a knitting needle to a flat end. Lay the needle on the table and stroke it once from the middle to the marked end with the + end of a bar magnet. Reverse the needle and stroke the unmarked end once with the — end of the magnet. Place the compass on the table and bring the marked end of the knitting needle to the west side of the compass with the needle pointing directly toward it. Mark the position of the marked end of the needle when the compass needle is deflected ten or fifteen degrees.

Turn the needle end for end and bring the pointed end into the first position of the marked end. Note the direction and the amount of the deflection. Stroke each end of the needle as before and test the deflection. Repeat until the deflection of the compass needle has reached a maximum, *i.e.* until the magnetism of the knitting needle is no longer increased by the process.

Conclusion. — State in your notes the polarization shown by each end of the knitting needle and the effect that each stroke had upon the extent of the deflection.

(b) By the use of a horseshoe magnet without stroking.

Apparatus. — Sewing needle; horseshoe magnet; compass; a thin card.

Method. — Lay the card upon the poles of the horseshoe magnet and place the needle upon it with the eye end over the + pole and the point over the — pole. Rap the needle sharply with a pencil or a knife handle. Test it for polarity with the compass. Repeat and test again until you have the maximum deflection.

Conclusions. — State the polarity of the needle and explain why it is magnetized. Has your needle been saturated in either experiment?

Suppose that the needle of a compass had lost its magnetism, how would you restore it and have the polarity the same as before?

Suggestions. — Test all iron pipes and rods about the laboratory. Where do you find the + pole? Where the — pole? Where the neutral point? Why are the rods magnetized?

EXPERIMENT 34

Study of a Single-fluid Galvanic Cell. El. of Phys.,
pp. 305-307

Apparatus. — A strip of sheet zinc; a similar sheet of thin copper; a tumbler two thirds full of dilute sulphuric acid (H_2SO_4 1 part, water 10 parts); a few drops of mercury; compass; connecting wires.

Method. — Stand the strip of zinc in the sulphuric acid and observe its surface. Do the same with the copper strip. Bring the upper ends of the strips into contact outside the liquid and observe any change in the action on the surface of each.

Remove both from the liquid and amalgamate the end of the zinc strip that was in the liquid by rubbing mercury over it. Repeat the experiments with the amalgamated zinc both alone and with the copper. Solder a copper wire to the upper end of each strip and connect the wires. Turn the apparatus so that the direction of the wires is north and south. Then hold the compass under each wire and determine the direction of the current. This can be done by holding the right hand so that the wire is between the palm of the hand and the compass needle. If the north end of the needle is deflected toward the extended thumb, the direction of the current in the wire is from the wrist toward the finger tips.

Conclusion. — What is the cause of the "local action" on the surface of the zinc before it has been amalgamated? How does amalgamating the zinc prevent this action? Which pole of the cell is + and which is - ?

EXPERIMENT 35

The E.M.F. of a Single-fluid Cell, and the Electromotive Series. El. of Phys., pp. 308, 312-314

Apparatus. — Strips of aluminum, carbon, copper, iron, lead, and zinc; a glass tumbler, or better the form of simple cell shown in Fig. 41; a voltmeter; dilute sulphuric acid; dilute hydrochloric acid; connecting wires; switch.

Method. — Make a cell using dilute sulphuric acid, and the copper and zinc strips. Couple the voltmeter to the cell and take a reading. Lift the strips nearly out of the liquid, keeping them at the same distance apart, and take the reading. Push the strips nearer together without changing their depth in the liquid, and read the voltmeter. Take a set of readings using the carbon strips with all the others in succession; take another set using the copper strip with all the others in succession, and so on until all possible combinations have been made. Wash the strips and take similar sets of readings, using dilute hydrochloric acid as the liquid.

Conclusions. — What effect does the extent of the surface of the strips in the liquid have upon the voltage of the cell? What effect does the distance of the strips from each other have upon the voltage? Is the voltage constant for some time with all the cells?

Suggestion. — Make a list of the substances used, arranging them in order, placing at the top the one that is positive to all the rest, next the one that is positive to all except the first, and so on to the last in the list, which will be negative to all

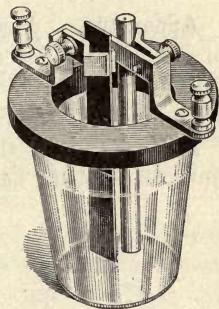


FIG. 41.

the rest. Make a list for each liquid used. Do the substances come in the same order in the two lists? What two substances give the greatest difference of potential in each?

EXPERIMENT 36

To study a Two-fluid Cell and to compare with it a Dry Cell. El. of Phys., pp. 308-311

Apparatus. — A cell like that used in Experiment 35; a strip of copper and one of amalgamated zinc; a small porous cell; dilute sulphuric acid; solution of copper sulphate; a dry cell; an ammeter; voltmeter; connecting wires; switch.

Method. — Pour the copper sulphate solution into the tumbler until it is about half full. Set the porous cup in the liquid and pour dilute sulphuric acid into the cup until the two liquids stand at the same height. Insert the copper strip in the copper sulphate solution and the zinc strip in the sulphuric acid. Couple the voltmeter to the cell and read the voltage. Couple the ammeter and the switch in series to the cell, and couple the voltmeter as in Fig. 42. Close the switch and read

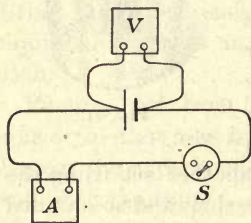


FIG. 42.

the ammeter and voltmeter. Leave the switch closed for five minutes. Read the voltmeter and ammeter. Open the switch and read the voltmeter. Close the switch again for another five minutes and repeat the readings. Do this for a half hour and tabulate your results. Repeat the experiments, substituting a dry cell for the two-fluid cell, and tabulate your results.

Conclusion. — The two-fluid cell is called a “closed circuit cell.” What evidence does the experiment give showing that it is adapted to this purpose? How does the dry cell compare with it in this respect? Would the dry cell answer for “open

circuit" work? Why? Write a description of the results of polarization in a cell.

Suggestions. — Couple a new dry cell to the voltmeter and make a record of its voltage. Couple four such cells in series and record their voltage. Couple the same four cells in parallel and record their voltage. Write the results of your experiment and the results of series and parallel coupling.

EXPERIMENT 37

Arrangement of Cells to produce the Greatest Current in a Given Circuit. El. of Phys., p. 316

Apparatus. — Several two-fluid cells, or any cells that will give a fairly constant potential; copper wire No. 18; German silver wire No. 30; a galvanometer with both high and low resistance coils; connecting wires; a switch.

Method. — Couple the cells in series and for the external resistance put 10 ft. of No. 18 copper wire, the low resistance coil of the galvanometer, and the switch. Close the switch and read the deflection. Couple the cells in parallel and read the deflection. Repeat both readings after replacing the copper wire by 10 ft. of German silver wire No. 30. Couple the high resistance coil of the galvanometer in the circuit and repeat all readings.

Conclusion. — From the readings taken in each case determine which is the better arrangement of cells for a low external resistance and which for a high external resistance.

EXPERIMENT 38

Effect of an Electric Current upon the Temperature of a Conductor. El. of Phys., p. 317

Apparatus. — Four or more cells; 10 ft. of iron or German silver wire No. 30; galvanometer; thermometer; connecting wire; switch.

Method. — Wind a part of the wire into a coil closely around the bulb of the thermometer, leaving the rest of the wire as a resistance. If the wire is not insulated, the turns of the coil must be pulled apart so that they do not touch one another.

Couple the coil, cells, galvanometer, and switch in series and send a current through the circuit. Take such a number of cells as will give a suitable deflection of the galvanometer, and such a galvanometer that a large current will be required to deflect it. Take simultaneous readings of the galvanometer and thermometer. Reduce the length of wire to about half and again send a current through the circuit and take readings.

Conclusion. — Does the passage of a current in a wire change its temperature? What is the change? Does the extent of the change depend upon the amount of the current?

EXPERIMENT 39

Lines of Force about a Current-carrying Conductor.

El. of Phys., p. 318

Apparatus. — A battery of six cells; a smooth card and support; insulated wire No. 18; six small compasses one half inch or less in diameter; switch.

Method. — Support the card horizontally and run the insulated wire vertically through it, connecting it in series with the cells and switch. Place the compasses on the card in a circle as close to the wire as possible.

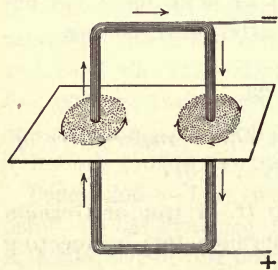


FIG. 43.

Conclusion. — Observe the direction taken by the compass needles both before and after the current is turned on. Make drawings of the same. Reverse the direction of the current in the conductor by changing the couplings, and observe. Write

the law of the relation of the current in the conductor, and the direction of the magnetic field around it.

Suggestion. — If a current of 20 to 30 amperes is at hand, a very good result can be obtained with iron filings sifted on the card around the wire. A good effect can be obtained with a battery current if the wire is wound into a coil, both branches of which pierce the card, as shown in Fig. 43.

EXPERIMENT 40

To study an Electro-magnet. El. of Phys., p. 321

Apparatus. — A rod of soft iron 4 in. long and a quarter of an inch in diameter; insulated copper magnet wire No. 18; two cells; iron filings; wire nails; compass; connecting wires; galvanometer; switch.

Method. — Wind the wire around the iron rod until nearly its whole length is covered, and fasten the ends of the coil to the rod with thread. Test the ends of the rod with the compass needle for magnetism. Couple a cell, the coil, galvanometer, and switch in series and close the switch. Test the two ends of the rod for magnetism.

Reverse the current in the coil and again test the rod. While the current is on, dip the end of the rod in a pile of small nails. Break the circuit and observe the action of the nails. Couple two cells in the circuit in the way that will give the maximum current, and while the current is on, insert the end of the rod in the nails.

Fix the rod in a vertical position and sift iron filings on a card supported horizontally on the upper end, and observe the lines of force.

Conclusion. — Make a drawing showing the relation between the direction in which the current passes about the rod and the polarity of its ends. What effect does the amount of current in the coil have upon the number of nails the rod will carry?

Suggestion. — Wind a solenoid in the form of Fig. 44. Send a current through it from a cell and observe the effect it has upon a compass needle placed at *A*, *B*, *C*, and *D* in the figure. Mark in your notes the direction of the current passing from the cell to the solenoid and its direction in the coil. Without changing

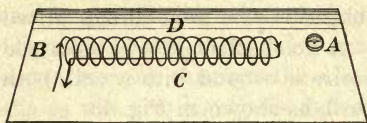


FIG. 44.

the position of either the solenoid or the compass, introduce a piece of gas pipe or any other iron core into the solenoid and explain the result.

EXPERIMENT 41

To make and study a Lifting Magnet. El. of Phys., p. 322

NOTE. — It may not be possible for all schools to make this experiment. Those schools which can make it, or some modified form of it, will find it most instructive and interesting.

Apparatus. — Lighting circuit as source of current; ammeter; lamp resistance board; special apparatus described below.

Method. — In order that an electro-magnet may have great lifting power it should have a small air gap and a short iron circuit, and the iron should be of high permeability; that is, it should offer little resistance to the lines of force.

An efficient form is shown in Fig. 45, a part of which is in section. *I* is the iron of the magnet and *I'* that of the armature. This is known as an iron-clad form, and fulfils the first and second of the required conditions. The coil *C* is wound upon a former, is wrapped with tape, and fitted into the groove in the iron. *W* is a wooden ring that serves to support the binding posts *PP'*.

To make this magnet, turn on a wood lathe patterns for the

magnet and armature.¹ Have castings made of iron or soft steel and file or turn the contact faces to make a good fit. Turn a wooden spool with a groove in it slightly smaller than the size of the coil, wind it full of magnet wire No. 24, then wind this coil with tape and give it a coat of shellac. It is a good plan to make a split spool as shown in Fig. 46, so that it will be possible to

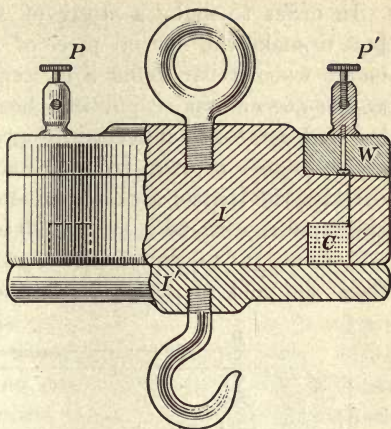


FIG. 45.



FIG. 46.

take out the screws that hold the halves together, and remove the coil without pulling it apart. Force the coil into the groove of the electro-magnet before the shellac is dry, and couple the wires to the binding posts as shown. Two holes must be drilled through the iron, through which the ends of the coil may be connected with *P* and *P'*. The dimensions may well be as follows:—

Diameter of magnet four and one half inches.

Outside diameter of coil three and one half inches.

Inside diameter of coil two and one half inches.

Depth of coil one half inch.

Thickness of armature one half inch.

The iron parts can be obtained from any machine shop if preferred.

¹ If there is a heavy iron casting with a flat face at hand, it can be used in place of the armature.

In order to make a study of the lifting power it will be best to make the special piece of apparatus shown in Fig. 47. Get a wooden bar about 8 ft. long and 2 in. or more square, and at one end, as *A*, put in a heavy screw hook. Weigh the bar and determine its center of gravity. Bore a half-inch hole at a distance of 1 ft. from *A* and drive a half-inch iron rod through the bar for a fulcrum. Put a large ring over the bar and from it suspend a weight, 20 to 50 lb. Weigh the ring and add its weight to that of the weight used. Suspend the magnet from the hook at *A* and fasten the armature to a screw eye in

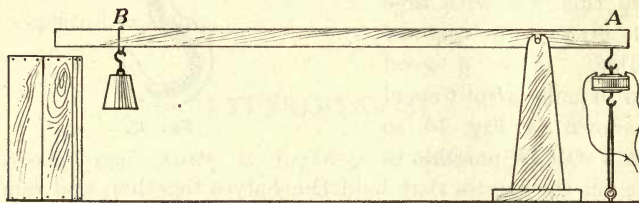


FIG. 47.

the floor. Couple the magnet coil to a lighting circuit with a lamp board and ammeter in series with it. Send the current through one lamp, slide the weight slowly along the bar away from the fulcrum, and record the position of the weight when the magnet is separated from the armature. It is well to put a box under the end of the bar at *B* to prevent its falling to the floor when the armature is pulled off. Take a reading of the current at the exact time of separation. Add another lamp and again find the position of the weight and the amount of the current. Keep adding lamps and taking readings until the current has reached 3 amperes. Too great a current will overheat the coil of the electro-magnet and may break the insulation.

Conclusion. — Make a curve showing the relation of the current passing in the coil of the electro-magnet to the lifting power of the magnet.

EXPERIMENT 42

Electroplating. El. of Phys., p. 325

Apparatus. — Cell; connecting wires; copper sulphate solution; large steel wire nails; glass beaker.

Method. — Scour the nails thoroughly with sandpaper and wash them off with clean water. Wind around the head of each a half dozen turns of copper wire from which the insulation has been stripped. Couple two or three cells in series and connect one nail with the + and the other with the — pole of the battery. Dip the nails into the solution of copper sulphate and observe what takes place on each nail. After the battery has been sending current for about ten minutes take out the nails and examine them. Wash and dry them and try the effect of rubbing each of them with an eraser.

Change the connections of the nails to the battery so that the one that was connected to the + will now be connected to the — pole and the one that was connected to the — will now be connected to the + pole. Dip the nails again into the solution and observe what takes place.

Conclusion. — What was deposited on the cathode, *i.e.* the nail connected with the — pole of the battery? What was set free at the anode, the nail connected with the + pole? Does the copper ion in the copper sulphate solution go in the same direction as the current in the solution or in the opposite direction? Answer the same question about the ions of oxygen. With what kind of electricity are the copper ions charged, + or — ?

EXPERIMENT 43

To study the Resistance of a Conductor. El. of Phys., p. 329

Apparatus. — A two-fluid cell; insulated copper magnet wire Nos. 27 and 30; German silver wire No. 30; a galvanometer; connecting wires; switch.

Method. — Put 5 ft. of copper wire No. 30 in series with the cell, galvanometer, and switch. Throw on the current and read the deflection. Couple in 10 ft. of the same wire and read the deflection. Couple in a double wire made of two wires like the last and read the deflection. Couple in 10 ft. of wire No. 27 and read the deflection. Couple in 10 ft. of German silver wire No. 30 and read the deflection.

Conclusion. — Compare the deflection obtained with the 5 ft. of copper wire and that obtained with the 10 ft. Compare the deflections with a single wire and with a double wire. Compare the deflection with the double wire No. 30 and that with the single wire No. 27. Compare the deflection with 10 ft. of copper wire and that with 10 ft. of German silver of the same size.

Do your readings indicate that the expression for the resistance of a wire, $R = K \frac{l}{d^2}$, is correct or not? In this expression,

K represents the relative resistance of different materials, l the length, and d the diameter of the wire. Refer to the wire table for the diameter of wires Nos. 27 and 30.

EXPERIMENT 44

Effect of Temperature on the Resistance of a Conductor.

Study of the Change of Resistance of an Iron Wire due to Change of Temperature. El. of Phys., p. 329

Apparatus. — Small iron wire; cells; galvanometer; a wooden spool; beaker of water; Bunsen burner; a quarter-inch iron rod; connecting wires; switch.

Method. — Wind the iron wire in a close spiral around the iron rod. Carefully remove the spiral and wind it around the spool so that the turns of the wire shall not touch one another. Place the spool with its coil in the beaker of water, submerging the entire coil. Couple it in series with the cell, galvanometer,

and switch. Send the current through the circuit and take a reading of the galvanometer deflection. Heat the water in the beaker nearly to the boiling point and repeat the experiment.

Conclusion. — Compare the readings of the galvanometer in the two experiments and state what effect increasing the temperature of an iron wire has upon its electrical resistance. How does the hot resistance of an incandescent lamp compare with its cold resistance? Does a rise of its temperature increase or diminish the resistance of carbon?

Suggestion. — If the beaker is looked upon as a calorimeter, it will be an interesting addition to the experiment to determine the number of calories given to the water by the electrical heating of the iron wire (compare Experiment 38), and to see whether it verifies the formula for the heating effect of a current; namely, $\text{Calories} = 0.24 C^2 R t$.

EXPERIMENT 45

To measure the Resistance of a Conductor by the Fall of Potential Method. El. of Phys., p. 337

If an electric current passes through a conductor, there must be a difference of potential between the two ends of the conductor. This is called the fall of potential through the conductor. If this fall of potential and the current that passes through the conductor are known, the resistance of the conductor can be found by substituting these values in the expression for Ohm's Law, from which $R = \frac{PD}{C}$.

Apparatus. — The conductor, the resistance of which is to be measured; an ammeter; voltmeter; several constant potential cells, or a lighting circuit as source of current; switch; rheostat; connecting wires.

Method. — Couple the conductor, rheostat, ammeter, and switch in series with the source of current, as in Fig. 48.

Couple the voltmeter as a shunt to the conductor. Put in all the resistance of the rheostat. Close the switch and read the ammeter and voltmeter at the same instant. This can be done by having one student give a signal to two others who do the reading. Reduce the resistance of the rheostat and take a second set of readings. Take a number of sets of readings, reducing the rheostat resistance each time until the current is as great as you wish to use.

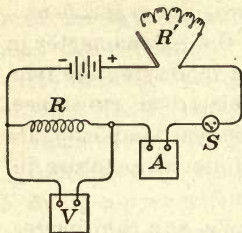


FIG. 48.

Conclusion. — Compute the resistance for each set of readings. Are the resistances the same? Would the change in temperature explain the differences? With a low-reading voltmeter and a large current this is a convenient and accurate method for the measurement of small resistances.

Suggestions. — It is often convenient to be able to set the arm of a rheostat at a known resistance. In order to have a permanent record for this purpose, measure the resistance of the rheostat by this method and make a curve from the results of your measurement that shall show the relation between the resistance of the rheostat and the different contact points.

Make a study of the parallel resistance of incandescent lamps by putting a number of 110-volt lamps of different candle power in a lamp board, as in Fig. 49. Find the resistance of each lamp and then the resistance of 2, 3, 4, etc., in parallel. Compare the resistance with that computed from the formula,



FIG. 49.

$$R = \frac{1}{\frac{1}{r} + \frac{1}{r'} + \frac{1}{r''} + \frac{1}{r'''}} \text{, etc.}$$

EXPERIMENT 46

The Distribution of Current over the Branches of a Divided Circuit. El. of Phys., p. 338

A divided circuit is one that provides two or more paths between two points. A study of the currents in the two branches of the circuit (called also shunt or parallel circuits) may be made as follows.

Apparatus.—Three ammeters; three rheostats; a number of cells or a dynamo circuit; connecting wires.

Method.—Couple the apparatus as in Fig. 50. It is evident that ammeter A will read the entire current and that its reading will be the sum of the readings of A' and A'' . Make a number of sets of readings, varying the resistance of R to control the main current and that of R' and R'' to control the current in the branches.

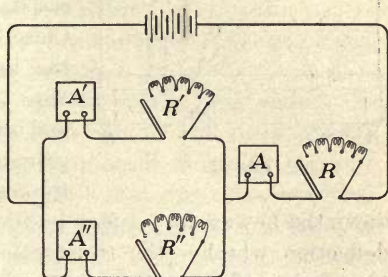


FIG. 50.

Conclusion.—The results of your experiments should show clearly the effect of changing the parallel resistances in a circuit upon the currents in the two paths.

Suggestions.—If the resistances of one of the rheostats, as R' , are laid off on the horizontal axis and the currents in A' on the vertical axis, the resulting curve will be a good example of an inverse change, *i.e.* one in which one value decreases and the dependent value increases.

If the three ammeters and rheostats are not at hand, use two galvanometers—one in each branch—and change the currents by putting in copper and German silver wires and interchanging them.

EXPERIMENT 47

To measure the Resistance of a Conductor by the Wheatstone Bridge. El. of Phys., p. 338

Apparatus. — A slide-wire bridge; constant voltage cell; resistance box; a sensitive galvanometer; four pieces of wire No. 30, each 10 ft. long, of copper, iron, German silver, and climax wire; connecting wires; switch.

Method. — Couple the apparatus as shown in Fig. 51, putting in the copper wire at X as the one to be measured first. Make an

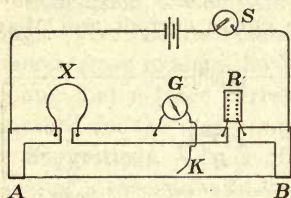


FIG. 51.

estimate of the resistance of the wire and arrange the plugs in the resistance box to read that amount. Close the switch and touch down the key K at the middle of the wire AB . Observe the direction and amount of the deflection of the galvanometer needle. Increase the resistance of the box and touch

down the key again. Judge by the direction and amount of the deflection whether the resistance of the box is too little or too much. Change the resistance of the box as required until there is no deflection of the galvanometer needle. If the resistances in the box are not small enough to give this result, it can be brought about by moving the key K towards A or B . When this position is found for K , the proportion $X : R = AK : KB$ holds, and hence $X \times KB = R \times AK$, that is, the *cross multiplications* of the bridge arms are equal. If K is at the middle of AB , it is evident that $X = R$. Find the value of X . In the same way find the resistance of all the wires.

Conclusion. — Since the wires are of the same length and diameter, the relation of their resistances will be the relation of their specific resistances and should be the same as that given in a table of specific resistance.

A very convenient form of the Wheatstone bridge is the portable testing set. This has the cells, galvanometer, resistance coils, and a form of plug resistance box to take the place of the slide wire, all in a small box that can be conveniently carried about.

Pupils cannot become too familiar with the different forms of the Wheatstone bridge, since it is applied in very many ways in practical work.

EXPERIMENT 48

The Internal Resistance of a Cell. El. of Phys., p. 341

(a) *To study the internal resistance of a cell.*

Apparatus.—A simple cell; low-resistance galvanometer, or ammeter; connecting wires; switch.

Method.—Couple the cell, galvanometer, and switch in series. Take a reading of the deflection of the galvanometer with the zinc and copper strips immersed to nearly the full length. Keeping the strips at exactly the same distance from each other, pull them up and clamp them in such a position that they are only immersed two thirds their length. Take a second reading of the deflection. Repeat with the strips immersed to but one third their length. Again clamp the strips so that their full length is immersed and separate them as far as possible, keeping them parallel to each other. Take a reading of the deflection. Repeat several times, reducing the distance between the plates each time until they are nearly touching.

Conclusion.—From a comparison of the records that you have taken, what is the effect upon the current of changing the area of the submerged part of the strips? Of changing the distance between the strips? Since the only change was in either the distance apart of the copper and zinc plates in the cell or the amount of the plate that was inserted in the

liquid, any change in the current would, from Ohm's Law, $C = \frac{E}{R}$, indicate an opposite change in the resistance of the cell. What changes in internal resistance does the experiment indicate? Does the internal resistance of a cell follow the law of resistance of a conductor? How do your results show this?

(b) To measure the internal resistance of a cell; the half-deflection method.

Since a cell is a generator of the electric current and polarization is apt to take place in it, the measurement of its resistance offers more difficulties than does the measurement of an ordinary resistance.

Apparatus. — The cells the resistance of which is to be measured; an ammeter that will give an accurate reading for small currents; rheostat; a testing set or Wheatstone bridge; connecting wires; switch.

Method. — Connect the rheostat, ammeter, switch, and the wire necessary to couple in the cell, and measure the resistance with the testing set when there is no resistance in the rheostat. Couple in the cell with the switch open. Close the switch and read the ammeter. This reading should be taken at the instant the needle comes back from its first throw, and before it begins to fall slowly. This slow fall will take place with all cells that polarize. Introduce resistance into the circuit by the rheostat until the ammeter reads just one half the former reading. Be careful to open the switch when the current is not needed.

Conclusion. — Call the first resistance measured by the testing set r , the resistance added by the rheostat R , the resistance of the cell x , and its electromotive force E . Then the first current will be given by the expression $C = \frac{E}{r + x}$; the second

current will be $C'' = \frac{E}{r+x+R}$. Since $C' = 2 C''$, and E is the same in both expressions, $\frac{E}{r+x} = \frac{2E}{r+x+R}$, from which we get $x = R - r$. Apply the method to a number of different cells and compute the resistance of each.

(c) *The voltmeter method.*

Apparatus. — A low-reading voltmeter; an ammeter for small currents; the cells the resistance of which is to be tested; connecting wires; switch.

Method. — Couple the apparatus as in Fig. 52. Take first the reading of the voltmeter when the switch in the ammeter circuit is open. Call this reading V' . Close the switch and take simultaneous readings of both the voltmeter and the ammeter. Call the voltmeter reading V'' and the ammeter reading C .

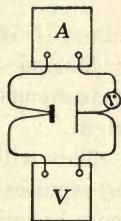


FIG. 52.

Conclusion. — Compute the resistance of the cell from the expression $R = \frac{V' - V''}{C}$. Why? This method is well adapted to the measurement of the resistance of a cell that has a small resistance, as the storage cell, for example.

EXPERIMENT 49

Effect of Cutting Lines of Force with a Conductor.

El. of Phys., pp. 344-347

Whenever a conductor passes through a magnetic field in which the lines of force are not parallel to the conductor, or whenever a conductor "cuts lines of magnetic force," an electric current is set up in this conductor if it is a part of a closed circuit.

Apparatus. — A bar magnet; a coil, called the secondary, consisting of 500 turns of No. 24 magnet wire wound upon a wooden spool about half as long as the magnet; a primary coil of 50 turns of No. 18 magnet wire wound upon a vulcanite or pasteboard tube, the coil when finished being of such a size that it will slip easily inside the secondary coil; a bundle of iron wires as core for the primary; a snap switch; a sensitive galvanometer, or millivoltmeter; a rheostat; cells; connecting wires. (See Suggestions below.)

(a) With the field of a bar magnet.

Method. — First determine the direction of current in the galvanometer that will produce a throw of the needle to the right.

This will require a very small current that may be obtained by connecting the galvanometer as a shunt to a short piece of wire in series with the cells and rheostat.

Connect the galvanometer in series with the secondary coil and thrust the + end of the magnet into the coil. Observe the direction of throw of the needle. Pull out the magnet quickly and observe the direction of the throw. Repeat, using the — end of the magnet.

Conclusions. — Suppose you stand in the magnetic field facing the direction toward which the lines of force are going. Suppose that you hold a conductor in your hands horizontally, and then allow it to drop so that its motion is vertically downward, what will be the direction of the induced current?

Make a drawing to illustrate these directions.

Does it make any difference whether the magnet or the coil is in motion, in producing the cutting of the lines of force?

(b) With the field of a primary coil.

Method. — Couple the primary coil in series with the cells, rheostat, and snap switch. Close the switch with no resist-

ance in the rheostat and make the same experiments with the primary coil as with the bar magnet in (a), both when the iron core is in the primary and when it is not.

Turn off the current and place the primary and its core inside the secondary. Snap the switch on and observe the direction and magnitude of the throw of the needle. Wait until the needle is quiet and then snap the switch off. Observe the direction and magnitude of the throw. Introduce resistance into the circuit with the rheostat, reducing the current in the primary, and repeat.

Conclusion. — Make a drawing to show the relative direction of the inducing current in the primary coil, and of the induced current in the secondary coil, both on starting and on stopping the current in the primary.

What is the duration of the induced current?

The cutting of the lines of force induces an electro-motive force. If the cutting conductor is part of a closed circuit, there will be a resulting current; its magnitude being proportional to the induced E.M.F.

What determines the magnitude of the induced E.M.F.?

Suggestions. — Very simple apparatus will serve for experiment (a), if necessary. A coil of 50 turns of copper wire No. 30, wound on a cardboard ring of such a size that it will slip freely over a bar magnet, serves for the secondary coil. A simple galvanometer can be made as follows: Fasten a horseshoe magnet to a board, as in Fig. 53. Wind an oblong coil of fine wire, No. 30, for example, and suspend it in such a way that it will hang between the poles of the horseshoe. A slight current sent through this coil will give it a throw that will determine the direction, at least, of the current, if the direction of the winding of the coil is known.

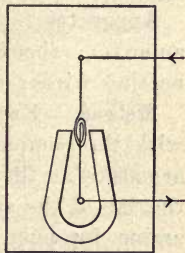


FIG. 53.

EXPERIMENT 50

To study a Dynamo. El. of Phys., pp. 352-359

In the dynamo the conductors in which the E.M.F. is induced are the armature wires *a*; the lines of force are in the air gap *g*, between the poles, *N* and *S*, of the field magnet *f*, and the core of the armature *c*. If the armature rotates in a clockwise direction, the lines of force are cut in such a way as to send the current through the armature coils in the direction indicated in Fig. 54.

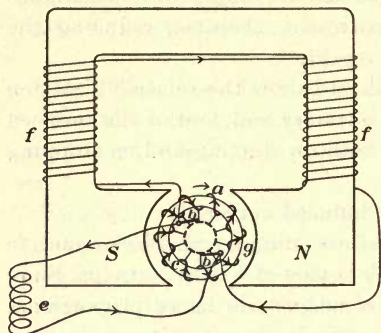


FIG. 54.

The current thus generated is taken off by the brushes *b*, as they come in contact with the commutator bars, and then goes through

the external circuit *e*. In the figure shown a part of the current goes around the field magnet coil *f*, and produces the magnetic field.

Apparatus.—A small shunt-wound dynamo; voltmeter; ammeter; rheostats; speed counter; a small compass; connecting wires; switch.

Method.—Examine the core of the field magnet for polarity with the compass before the machine is started. Run the armature at the normal speed, which may be determined by the use of the speed counter, and again examine for polarity. Couple the terminals of the machine to the ammeter and one of the rheostats in series, and the voltmeter in parallel (Fig. 55). Introduce a resistance into the circuit by the rheostat and run

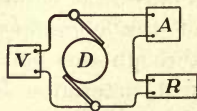


FIG. 55.

the armature at the normal speed. Take readings of the ammeter, voltmeter, speed counter, and resistance. Reduce the resistance and repeat, running the armature at the same speed. Run the armature at different speeds, keeping the resistance the same and taking readings of the ammeter and voltmeter. Introduce resistance into the shunt field circuit by the use of a rheostat and run the armature at normal speed with the same resistance in the main circuit as at first. Read the voltmeter. Disconnect the shunt field entirely from the brushes, run the armature at normal speed, and read the voltmeter.

Whenever two or more instruments are read in this experiment, the reading should be done at the same time.

Conclusion.—Tabulate your results and answer the following questions:—

What effect upon the voltage of a dynamo does speed have? Why?

What effect upon the current does resistance in the main circuit have? Why?

What effect upon the voltage does resistance in the field coils have? Why?

Why does the voltage of a dynamo increase as the speed rises from zero to the normal rate?

When you disconnect the shunt field circuit from the brushes and rotate the armature, why do you get any reading with the voltmeter?

EXPERIMENT 51

To study an Electric Motor. El. of Phys., pp. 359–361

The cause of the rotation of an electric motor can be explained by considering the mutual action between the magnetic lines of force in the air gap generated by the current in the field coils and that generated in the same space by the current in the armature wires. Figure 56 represents the lines of force of the field passing across the air gap from the field pole to

the armature core, and the circular lines of force around the wire due to the current in the wire.

The action of these two magnetic fields upon each other causes the wire to be pushed down from above and pulled in the same direction from below.

Since the armature wires are fastened to the circumference of the core and since a similar action is taking place on every armature wire, the result is a rotation of the armature.

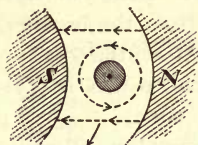


FIG. 56.

Apparatus.—A small shunt motor that can be run by a battery of a few cells, or a 110-volt motor on a lighting circuit; ammeter; voltmeter; three rheostats, R , R' , R'' ; connecting wires; speed counter; switch.

Method.—Examine the connections and wiring of the motor. Insert one rheostat, R , in the armature circuit, and another, R' , in the shunt field circuit. Couple the voltmeter as a shunt to the terminals and put an ammeter in series with the feeding wires. Each rheostat shown in Fig. 57, which shows

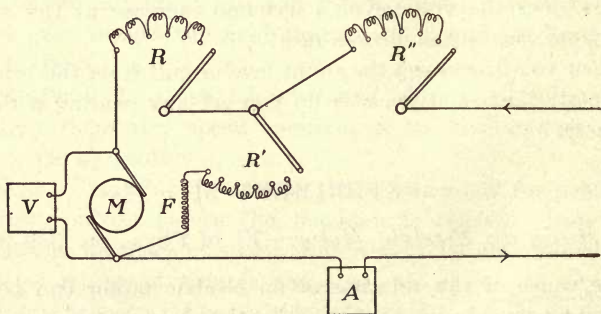


FIG. 57.

the connections, has an extra point which can be used as a switch. Hold the armature still and close the circuits with resistance in R'' and none in R and R' . Take readings of

both the ammeter and the voltmeter and compute the parallel resistance of the armature and the shunt field coil. Make the proper connections and take readings from which the resistances of the armature and of the shunt field coil can be computed. Send the current through the shunt field coil, cutting out all the resistance in rheostat R' , then send the current through the armature, leaving all the resistance in rheostat R . Reduce the resistance of R until the armature begins to turn. When it has come to a constant speed, take simultaneous readings of the ammeter, voltmeter, and speed counter. Reduce the resistance of R still more, and when the armature has again come to a constant speed, take another set of readings. Change the resistance of the rheostat until the motor is running at its normal speed and again take a set of readings.

Conclusions.—Why does the voltmeter read higher when the motor is running at its full speed than when the speed is low?

What is the effect of an increase of speed upon the ammeter readings? Why?

What is the effect of loading the motor?

Suggestions.—The rheostats that have been used in this experiment are replaced in practical work by a single motor starting box which has two rheostats in it, one for the armature and one for the shunt field. In this starting box the first contact sends the current through the shunt field coil before it is sent through the armature. Do you see the reason why?

An interesting experiment is to run the motor at full speed and then suddenly cut off the feeding current from the armature while it is left on the field coil. Watch the voltmeter from the time the current is cut off until the motor stops and notice the effect of the “back electro-motive force” of the motor.

This description of the experimenting to be done with the dynamo and motor may look rather formidable. Follow

it out step by step; do as much as you can, and you will find that each step is simple and that the more you do the clearer will be your understanding of the action of these two machines.

EXPERIMENT 52

Study of an Electric Bell. El. of Phys., p. 363

(a) *A simple circuit.*

Apparatus. — Electric bell; push button; cell; connecting wires.

Method. — Couple the apparatus in series. Study the connections. Find what adjustments give the best results and trace the path of the current.

Conclusions. — Make a drawing showing the connections. How would you modify the connections to make a single-stroke bell? Experimentally prove your answer.

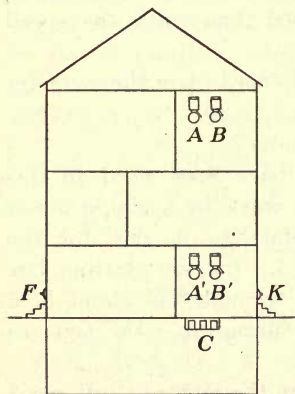


FIG. 58.

(b) *Two bells rung from a single push button.*

Apparatus. — Cells; two bells; a push button; line and connecting wires.

Method. — Connect the two bells — which should be of a different rate of stroke — first in series and then in parallel, in series with the cells and push button.

Conclusion. — Make a drawing of the connections used and state which method of coupling up the bells, series or parallel, gives the better results. Explain why.

(c) *A house bell circuit.*

In Fig. 58, the push button *F*, at the front door of the house,

rings two bells, A in the third floor and A' in the kitchen. The push button K , at the kitchen door, rings the two bells B and B' . Make a drawing of the wiring, the battery being in the basement at C . After working out the connections in the drawing, couple up the apparatus and test your plan.

EXPERIMENT 53

The Electric Telegraph. El. of Phys., pp. 363–366

(a) *A short-line telegraph.*

Apparatus. — A telegraphic outfit consisting of two cells, line and connecting wires, two keys, two sounders.

Method. — Connect the apparatus in series. Examine the construction of key and sounder. Test the core of the sounder electro-magnet for magnetism, both when the key is open and when it is shut. Operate the circuit from each key.

Conclusion. — Make a drawing showing the connections. Trace the current in its path through the circuit and explain the reason for the action of each part of the outfit. How does the sounder differ from an electric bell?

(b) *A long-distance telegraph line.*

Since the line is long, its resistance will be large, and it is necessary to use that form of electro-magnet called a relay. This has a high resistance and its function is to close and open a local circuit containing a battery and sounder.

Apparatus. — A telegraph outfit consisting of several cells, two relays, each of 150 ohms resistance, a 100-ohm coil, two keys, two local circuits consisting of cell, sounder having a resistance of 1.5 ohms, and connecting wires.

Method. — Connect up the apparatus somewhat as in Fig. 59. Study the connection and trace the current when the keys are closed. The satisfactory working of the apparatus will depend

upon the proper adjustment of the parts of the relays and sounders. Find under what conditions they work the best.

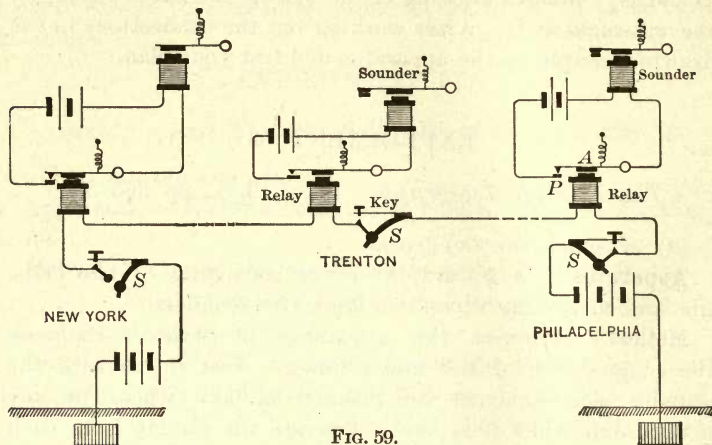


FIG. 59.

Conclusion. — Make a drawing of the circuit and describe the functions of each part of the apparatus.

Why is a relay necessary?

Why is it desirable to have a sounder?

EXPERIMENT 54

Intensity of Illumination. The Bunsen Photometer. El. of Phys., p. 384

(a) *To find the relation between the intensity of illumination and the distance.*

Apparatus. — Lamp; scale; two screens, each 1 ft. square; cardboard disk 1 in. in diameter.

Method. — Mount the screens and disk so that the centers of all shall be in a horizontal line. Make a small round hole in the middle of one screen. Place the lamp close to the perforated screen, and the disk at a distance of 1 ft. from the screen (Fig. 60). Place the second screen 2 ft. from

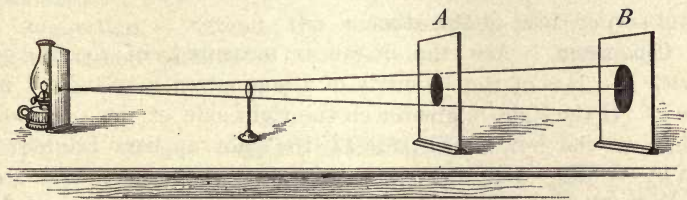


FIG. 60.

the source of light as shown at *A* in the figure, and measure the diameter of the shadow cast by the disk. Place the second screen at *B*, 3 ft. from the source of light, and measure the diameter of the shadow.

Conclusion. — How do the diameters of the shadows compare with that of the disk? How do the areas compare? If the disk were removed, the light which now falls upon it would fall instead upon the area of shadow, in each position of the

screen. Since the intensity of illumination is measured by the quantity of light that falls upon a unit surface, what is the law of the intensity of illumination as shown by your experiments?

(b) To find the relation between the intensity of illumination and the distance by means of a Bunsen photometer.

Apparatus. — A Bunsen photometer (see Suggestion below); five paraffin candles; blocks for supporting the same.

Method. — Mount one candle in the middle of one block and four side by side on the other. Place the single candle at one end of the photometer box and the four at the other end. Move the spot box back and forth until a position is found where the spot disappears when viewed in the mirrors. Measure the distances from the lights to the middle of the spot box. Change the positions of the candles and make a re-determination of the position of the spot box and a new measurement of the distances. Repeat with one candle at one end and two or three at the other.

Conclusion. — Are the distances measured in accordance with the law of the intensity of illumination investigated in (a)? If the light is greater on the right side of the spot box than on the left, which side of the spot appears brighter? Why? Why does the spot disappear when both sides are equally illuminated?

Suggestion. — A Bunsen spot box can be made as follows: In the middle of a piece of unglazed white paper, put a drop of melted paraffin. Heat it over a lamp until the spot is about half an inch in diameter and transparent. Cut a hole an inch and a half in diameter in a thick card three inches square, and paste the paper over the hole with the spot in the middle. Fix this in a vertical position and arrange two small mirrors as shown in Fig. 61. The images of the two sides of the spot can then be observed at the same time, and compared directly.

If the spot card and the mirrors are placed in a box with the ends and part of one side removed, as in Fig. 61, the apparatus can be used in an ordinary laboratory. If this is not done, the work should be carried on in a darkened room.

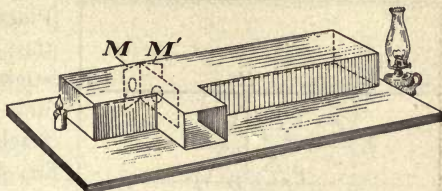


FIG. 61.

(c) *To determine the candle power of a gas or lamp light.*

Apparatus.—The Bunsen photometer of (b); the lamp to be tested.

Method.—Substitute the lamp for the four candles and determine the position in which the spot disappears.

Conclusion.—Compute from the measured distances the candle power of the lamp, assuming that the candles used are standard.

Suggestion.—Extend the measurement to incandescent lamps if convenient.

EXPERIMENT 55

Law of Reflection from Plane Mirrors. El. of Phys., p. 387

Apparatus.—A large sheet of paper; a piece of ordinary mirror with one straight edge or a similar piece of plate glass with one side painted black; a straight-edged ruler; pins.

Method.—Pin the sheet of paper to the top of a table and draw a straight line AB across the middle of it (Fig. 62). Stand the mirror upon its edge with the reflecting surface directly over the line. In an ordinary mirror the reflecting surface is the back of the mirror; in the plate glass blacked

on one side it is the front surface of the glass. Stick a pin vertically in the paper about 10 cm. in front of the mirror, as at P in the figure.

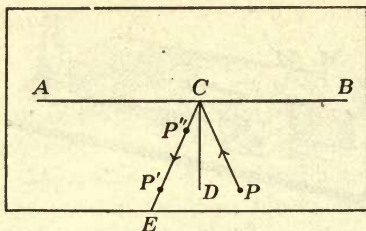


FIG. 62.

Place the eye at the edge of the paper, as at E , and stick a second pin at P' in line with the image of P . Stick a third pin at P'' also in the line of the image. Remove the mirror and draw a line through $P'P''$ until it strikes the line

AB at C . Draw a perpendicular CD to the line AB . Draw the incident ray PC and measure the angle of incidence PCD and the angle of reflection DCP' . Repeat for different positions of P .

Conclusion.—How does the angle of reflection compare with the angle of incidence?

Suggestion.—If the sheet of paper used is cross-section paper, the angles can be measured with considerable accuracy by means of the small squares.

EXPERIMENT 56

To determine the Position of an Image in a Plane Mirror.

El. of Phys., p. 389

(a) *The image of a point.*

Apparatus.—The same as that used in Experiment 55.

Method.—Draw a line AB (Fig. 63) and place the edge of the mirror on it as in Experiment 55. Stick a pin vertically at P and sight across it to its image, moving the eye to position E , such that the eye, P , and the image of P will be in a straight line. Stick another pin at C in line between P and its image. Move the eye to one side as at E' and stick a pin P' in line

with the image of P . Stick another pin at the edge of the mirror at D . Remove the mirror and draw lines from P to C and from P' to D and prolong them until they meet at p . Then p will be the position of the image of P .

Conclusion.—How does the distance Cp compare with the distance PC ? What direction has the

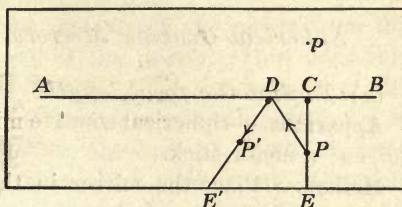


FIG. 63.

line Pp with respect to the line AB ? State a rule for finding the position of the image of a point in a plane mirror.

(b) *The image of an object.*

Apparatus.—The same as that used in (a).

Method.—Draw a triangle CDE (Fig. 64) on the paper in front of the mirror. Determine the position of the image of each vertex of the triangle, and call the images of C , D , and E , respectively, c , d , and e . Connect these points, forming the triangle cde . Measure the sides of both triangles.

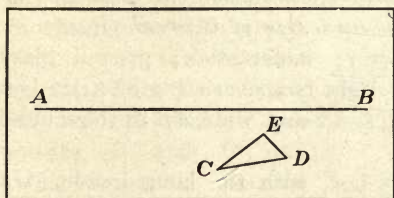


FIG. 64.

angle itself? How does the image compare in position and character?

Suggestion.—Lay one mirror on a table and fix a second mirror vertically beyond it so that the edges of the mirrors make a good joint. Hold a pencil upright in front of the vertical mirror and study its image in both mirrors. Study your own image when your face is near the mirrors.

EXPERIMENT 57

Spherical Concave Mirrors. El. of Phys., p. 393

(a) *To find the focal length.*

Apparatus.—Spherical concave mirror; a small ground glass screen; a meter stick.

Method.—Place the mirror in the sunlight, facing the sun, and focus the image of the sun on the ground glass. To do this, move the screen back and forth until the position is found in which the spot of light is smallest.

Measure the distance from this point to the mirror.

The distance between the mirror and the screen in this experiment is the focal length of the mirror, and the position of the image of the sun is the principal focus.

Conclusion.—Make a drawing showing the path of the sun's rays to the mirror, and construct the path of the reflected rays.

(b) *To determine the relation between the position of the object and the position and size of its real image.*

Apparatus.—Concave mirror; meter stick; ground glass screen; candle or gas lamp; light box, consisting of a tin box with a vertical slit, 2 cm. long and 2 mm. wide, cut in the middle of one side.

Method.—Place the light box, with the lamp inside, at a greater distance than the principal focal length from the surface of the mirror. Let this be nearly in the line of the principal axis of the mirror, and move the screen back and forth until the image is clearly outlined upon it.

Measure the distance of the screen and of the light box from the mirror, as well as the length of the image.

Move the light box and the screen until the image is of the same size as the object, and measure the distance of both from the mirror.

Conclusion.—Compute the focal length of the mirror from the equation $\frac{1}{F} = \frac{1}{D_o} + \frac{1}{D_i}$, in which D_i is the distance of the image from the mirror, D_o the distance of the object from the mirror, and F the focal length of the mirror. How does this computed distance compare with the measured distance of the image from the mirror when the image was the same size as the object? Make a drawing showing the path of some incident and reflected rays in the first experiment. Compute the radius of curvature of the mirror.

EXPERIMENT 58

The Index of Refraction of Water. El. of Phys., p. 400

Apparatus.—A six-inch battery jar; the device shown in Fig. 65, which is made as follows:—

Saw out a board FH of the general shape shown in the figure, with a projecting part that fits into the top of the jar. Run a wooden rod through two guides G and G' and drive a pin in the rod at A . Mark off a metric scale along the rod, taking A as the zero of the scale. At B , a point 8 cm. from the middle line of the rod, drive in a second pin. Along the side of the board CD lay off a scale with

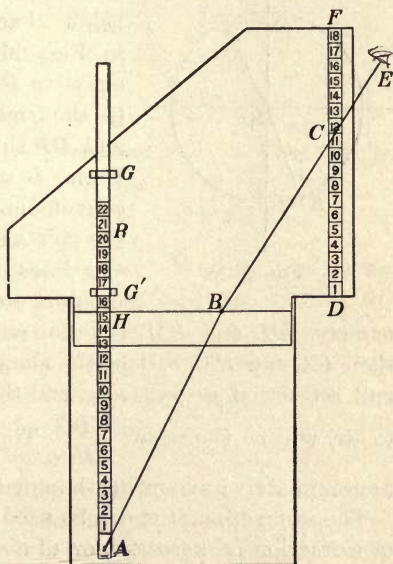


FIG. 65.

its middle line 8 cm. from B , having its zero on a level with B .

Method.—Level the jar and pour water into it until it reaches B . Place the eye at some point, as E , and holding a pin on some division of the scale FD , as C , move the rod up or down until the point A seems to be in the straight line EB .

Conclusion.—Since the horizontal distance of B from both scales is known when the board is made, the measurements are enough to determine the index of refraction of water (water to air). Do this for several positions of A and take the average.

Suggestions.—On a sheet of cross-section paper, place the point B at the intersection of two cross lines and draw pencil

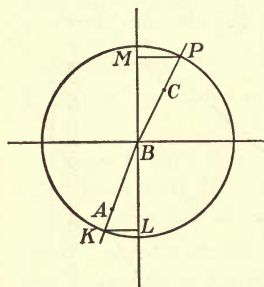


FIG. 66.

lines through these for axes. Locate A a distance equal to AH (Fig. 65) below B and 8 cm. to the left of it, as in Fig. 66, then locate C a distance equal to DC (Fig. 65) above and 8 cm. to the right of B . Draw lines BK and BP through these points from B . From B as a center, and with any convenient radius, draw a circle. From the points in which the circle intersects the lines BK and BP , drop perpendiculars to the vertical axis ML ; namely, KL and PM . If the radius BP is taken as unity, then KL and PM will be the sines of the angles of incidence and refraction respectively, and the index of refraction, water to air, will be the ratio $\frac{KL}{PM}$. These distances may be found

approximately by counting the squares on the cross-section paper.

The same apparatus can be used also to determine the index of refraction of kerosene, or of a saturated solution of salt in water.

EXPERIMENT 59

To determine the Index of Refraction, Air to Glass.

El. of Phys., p. 405

Apparatus. — A rectangular block of plate glass with polished edges; a metric scale; sheet of paper; pins.

Method. — Place the plate of glass upon the middle of the sheet of paper and trace its outline with a sharp-pointed pencil (Fig. 67). Suppose this to be MN in the figure. Stick two pins at A and B in such positions that a line drawn through them will make an angle of about 45° with the side of the glass plate. Sight the two pins from the other side of the plate and stick two pins C and D in such positions that all four pins seem to be in exact line. Remove the plate and draw the lines AB , BC , and CD . At B construct a line FE ,

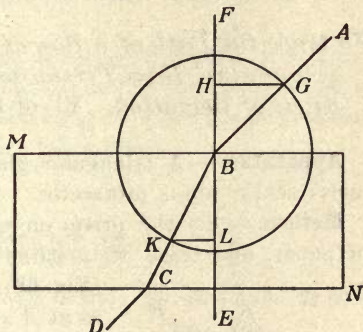


FIG. 67.

perpendicular to the edge of the plate. With B as a center describe a circle. Where this intersects the lines AB and BC drop perpendiculars to FE , namely, GH and KL , and measure them. If BG , the radius of the circle, is taken as unity, then the line GH is the sine of the angle of incidence and the line KL is the sine of the angle of refraction. Measure these lines and determine the value of the index of refraction from air to glass. With C as a center draw a circle and determine the value of the index of refraction from glass to air. Is there any relation between this value and the former one? Repeat for a different angle of incidence.

Conclusion. — How does the direction of the ray CD compare with that of the ray AB ? Why?

How is a ray of light affected on entering an optically denser medium?

How is it affected when it enters a medium that is optically rarer?

Do your different determinations prove that the index of refraction is a constant?

EXPERIMENT 60

To trace the Path of a Ray of Light from Air through a Triangular Glass Prism and into the Air again. The Angle of Deviation. El. of Phys., p. 406

Apparatus. — A triangular glass prism; a sheet of paper; meter scale; pins; protractor.

Method. — Set the prism on end in the middle of the sheet of paper, and trace its outline with a sharp-pointed pencil (Fig. 68). Stick two pins in the paper as at A and B in such position that the line AB will make an angle of about 45° with the side of the prism. Stick two pins C and D on the other side of the prism in such positions that the four pins seem to be in exactly the same straight line. Remove the prism. Draw perpendiculars to the sides of the prism at B and C . Determine the index of refraction as in Experiment 59, and measure the angle of deviation AEF .

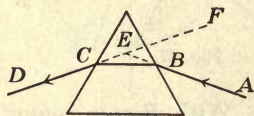


FIG. 68.

Conclusion. — The angle of deviation measures the change in the direction of the incident ray. Show on your drawing the direction the ray AB would take if the prism were not there.

In what direction is a ray of light bent by a triangular prism?

EXPERIMENT 61

To determine the Focal Length of a Converging Lens.

El. of Phys., p. 409

Apparatus. — Converging lens; ground glass screen; meter scale.

Method. — Place the lens in the sunlight and focus the image of the sun upon the ground glass. Adjust the position of the ground glass until the image is the smallest possible. Measure the distance of the screen from the lens. This is the focal length of the lens.

Conclusion. — Make a drawing showing the path of the incident rays before they enter the lens and of the emergent rays as they leave the lens to form the image. Place a match at the focus of the lens. Explain what takes place.

EXPERIMENT 62

Conjugate Foci of a Converging Lens. El. of Phys., p. 410

Apparatus. — Convex lens; the light box used in Experiment 57 (b); a ground-glass screen with a centimeter scale marked on it; meter stick.

Method. — Mount the apparatus so that the centers of the slit in the light box, the lens, and the scale on the screen are in the same horizontal line. Arrange the distance between the light box and the lens and between the screen and the lens until the image of the slit is of exactly the same length as the slit itself. Measure the distance of the object and of the image from the lens. Change the relative distances until you get an image that is smaller than the object, and then until the image is larger than the object. Measure both distances and the size of the image in each case.

Conclusion. — What relation is there between the distance of the image from the lens and the size of the image? Substitute your measurements in the formula $\frac{1}{F} = \frac{1}{D_o} + \frac{1}{D_i}$, and from this find the focal length. In this formula F is the focal length, D_o is the distance of the object from the lens, and D_i is the distance of the image from the lens. How does this focal length compare with that obtained in Experiment 61?

Suggestion. — An optical bench or support, such as is shown in Fig. 69, can be easily made and furnishes a ready means of

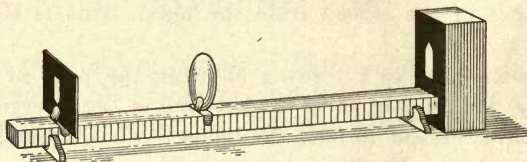


FIG. 69.

taking the measurements. By cutting one end of the slit in the form of a V and the other end square, it will be possible to determine in each case whether the image is upright or inverted.

EXPERIMENT 63

The Study of a Photographic Lens. El. of Phys., p. 435

Apparatus. — A photographic combination lens composed of two single lenses of different focal lengths; light box; screen; optical bench shown in Fig. 69.

Method. — Support the lens on the bench and determine its focal length from several sets of measurements. Unscrew the front lens from the setting and determine the focal length and size of image of the back lens. Take out the back lens, put the front lens back in the fitting, and determine its focal length and the size of the image,

Conclusion.—How do the three images compare in size? How do the focal lengths compare? Under what conditions would you use each lens in taking a picture?

Suggestions.—The filament of an incandescent lamp used as object gives a good sharp image in this experiment. If a tripod and camera box are at hand, the experiment can be made by using a window as the object. Examine the effect of using the two single lenses and the combination on a landscape.

Replace the lens by a piece of tin with a hole, a millimeter or less in diameter, in its center. Study the images obtained on the ground glass at different distances between ground glass and pinhole. Explain differences in size and amount of illumination of images.

Make a photograph of a building with a distinct outline, using a pinhole instead of a lens.

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